STUDIES IN
ADVANCED PHYSIOLOGY

RETTGER

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Fig. 148.—DIAGRAM OF CEREBRAL LOCALIZATION. (After Osler, based on the researches of Hitzig, Fritsch, Ferrier, and Beever and Horsley.)

STUDIES

IN

ADVANCED PHYSIOLOGY.

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PREFACE.

There are two extremes open in writing a brief treatise on any natural science. One is to state briefly and explicitly those facts which are seriously questioned by no one. It is to enumerate and tabulate what is definitely known about the subject. In the field of animal physiology there is much which is "settled" information, and which it is believed, will not be materially changed by the developments of the future. Most of the gross anatomy is finished, by no means all, but many points in histology are determined, while in pure physiology there are fewer things that are considered explained. Thus the phenomena of respiration and the dynamics of the blood flow are to a very large extent known in terms of chemical and physical laws. To limit a book to this would be to make it stereotyped, dead, and leave the reader with the impression that physiology like Sanskrit was finished, and like every finished problem had no longer a living interest of its own. Most of the ordinary text-books err on this side. They state *ex cathedra*, fact after fact, they seldom give the reasons which have led physiologists to adopt the views in question, and they seldom leave the idea that many things are still being studied with the hope that more study will give new light. Most text-books leave the mind of the student with the belief that all has been told, that there is nothing more to add, and that therefore there is no need for him to try to improve on the text-book, by making his own observation. The feeling of the authority of the text-book in physiology has robbed many a student of the desire to investigate the subject further. Like the Scholastics of the Middle Ages they turn to the book as to Aristotle, fully convinced that all knowledge is contained in it, and that what is not contained is impossible of access.

The other extreme is to give in detail all the scientific controversies of the past and present. It is to state indiscriminately pros and cons until the conviction settles over one that nothing is definite and all is confusion. Especially true is this when these conflicting views are at once presented to the beginner in the subject.

There are in physiology, as, possibly, in all other sciences, many problems at present which admit of different interpretations, and which must be referred to the investigations of the future for their correctness or their faultiness. It would not be treating the reader right to shower him with all sides of these questions, but the author has endeavored to present that view in each case which seems most generally accepted by scientific men, and awaiting future verifications to show the value of the claim. By taking this median course it is believed that the book will give to its readers all of the main known facts, and in addition acquaint them with many of those questions which are now demanding the attention of physiologists. This will put the science of physiology in its true light, it will show that it is a living science, still at work trying to interpret living problems. While it will show the present limitations of our knowledge it will suggest future possibilities.

It is hoped that the study of this book may result in a more lively appreciation of physiological phenomena, and an added interest in teaching the subject in our common schools.

It has been the aim to choose the illustrations for this book with the greatest possible care. They have been selected from quite a number of sources, and the proper credit has in each case been given with every figure. Quite a number of the histological illustrations are from Schäfer's *Essentials of Histology*. The author desires hereby to thank Messrs. Longmans, Green & Company, the publishers of that prince of text-books, Quain's *Anatomy*, for their permission to reproduce several of the illustrations found therein. The colored plates on the circulation of the blood have been made possible by their courtesy. The author is also under many obligations to D. Appleton & Company, publishers of Osler's *Practice of Medicine*, for permission to reproduce the colored plates illustrative of the nervous system.

LOUIS J. RETTGER.

Terre Haute, Indiana,
Aug. 12, 1898.

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INTRODUCTION.

What are the reasons that entitle the subject of physiology to a place in the common school curriculum? There are now so many subjects, on the educational value of which most educators are agreed, that unless physiology can do for the student what these do, it ought to give way to better fields of study.

In many cases no doubt it is taught simply because it is prescribed by law, and its injunctions are not questioned. In other cases its study is considered desirable, or even necessary, because physiology concerns itself so largely with hygienic considerations, and so is believed to exert a helpful influence on the general health. Possibly this is the main purpose our legislators had in mind when, by statute, physiology was made one of the common school branches. No one will deny the value, in fact the necessity, of having clear conceptions of hygienic rules and thoroughly understanding the laws of sanitation. It is the author's firm belief that if the knowledge of the nature of contagious and infectious diseases and of the means of their spreading, was more generally possessed, perfected sanitation would be declared a necessity, and the public health would be greatly improved. Such a result would repay a thousand times the cost of teaching such practical information. It is however a question whether it usually pays to have the study of physiology degenerate into formal rules of health, and recipes for disease. Such formal, theoretical knowledge seldom becomes of practical benefit. Most of us eat what our pocketbooks can afford and what experience shows agrees with us. We regulate our exercise by the amount of time available, and our inclination to take it. The desirability of bathing arises from something deeper than a mere intellectual perception of its value.

The tramp probably possesses, in some instances, a theoretical knowledge of the efficacy of soap and water, but it does not therefore become a practical belief.

In teaching small children it is of course desirable to make almost all the work of this hygienic character. Physiology is a science that pre-supposes some knowledge of physics and chemistry, and that cannot be assumed in really elementary classes. In addition small children have a morbid curiosity aroused when dealing with anatomical structures that is frequently productive of more evil than good. But with advanced classes physiology can be studied to the greatest advantage, provided that we do so in a scientific way. While in a strict sense physiology does not at all include anatomy, either gross or minute, yet as generally conceived it is made to include this, and in such a sense it is used by the author. While pure physiology is a science of experiments, like physics and chemistry, and not a science of observation like botany and zoology, and as from the difficulty of the experiments, not many of them can be repeated by the student himself, yet there are numerous simpler experiments of deepest physiological import which the student can perform for himself. Some experiments in artificial digestion with prepared extracts, the nature of the flow of liquids in iron and rubber tubes to illustrate circulation, the phenomena of blood coagulation, and finally the many experiments to be made in the study of the special senses, all these will afford abundant opportunities to perform experiments of the highest educational value. But it is when we include anatomy that the opportunities are greatest. It is never necessary in elementary instruction to call to aid vivisections, or even ordinary dissections of a nature often calculated to be repulsive. Let all these be proscribed. But the meat market itself will afford a multiplicity of material which will serve to illustrate all the more important fields of anatomy. Now it is believed that while a large part of the matter of physiology must be informational, and although this is often

of the greatest value, the best thing this subject can do for the student is to allow him to make his own observations as far as possible, and to make his own interpretations of experiments from related facts out of his own experience. There is not so much educational value in knowing that the heart possesses auricles, ventricles and valves, as there is in finding and understanding them when a real heart is being examined. There is an endless difference in mental value between learning a few curious things about the brain from the book or a cheap model, or even the description of a teacher, and in studying for ourselves, in detail, the varied anatomy of a real sheep's brain. One leaves us with hazy and dim ideas, the only real, tangible thing of which are the words to symbolize them, but the other results in real, definite, and lasting information. To have dissected out the salivary glands on the sheep's head, furnished by the meat market; to have seen the Eustachian tube; to have cut out the tonsils; observed the large circumvallate papillæ on the tongue; to have seen the lens and separated the coats of the eye; to have hunted for and found the middle ear with its chain of bones, possibly to have laid open the cochlea; to have seen all these things on a single sheep's head, will be of more lasting benefit and real educational worth than the ability to repeat from memory a chapter at a time of the latest edition of Quain's *Anatomy*. If, to carry the suggestion a little further, the student could observe and study with his own eyes the sympathetic system as it hangs displayed in every meat market, if he could but see one ganglion, one nerve trunk, and really learn to know it, if he could grasp with the fingers of his hand as well as those of his mind a single typical gland, crush with his thumb but one lymphatic nodule to know it, if in short he could get a *living* knowledge of the more important structures alone, he would not only have acquired facts which are indelible and can be turned to practical advantage, but he will have acquired a discipline in their acquisition which will give added power to the entire mind. Furthermore, and possibly

best of all, he is acquiring new facts in the way he will be obliged to acquire them when he leaves the school, and when there will no longer be a teacher to diagram every difficulty on the board in colored crayons, and when the student will no longer be carried each day "three pages in advance."

By making his own actual observations on actual tangible material he is not only training his powers of observation which are directly concerned, but by the care required to verify his observations, and by strict reasoning of the mind to properly interpret his observations, he is developing all those faculties of mind which are required in the acquisition of any new truth. He will learn what it often costs to make but one point, he will see what painstaking efforts it frequently requires to establish but one new fact, and he will not be discouraged when later on he finds it hard to make progress. He will know that to learn but one point as it ought to be learned is making more real progress than to have many poured into him. He will have somewhat of a criterion by means of which to gauge his own pace. It is certainly an attitude of mind brought about by scientific study not to accept too quickly what seems still unproved, be it from the assurances of the patent-medicine quack to the politician with his latest schemes on finance. Huxley compared knowledge with the virus of vaccination. When the virus is fresh, when it comes directly from its original source, it is wonderfully potent, but passed through the tissues of other animals it is gradually weakened and may finally have no effect at all. So knowledge gained firsthand, from the objects themselves, from the experiments themselves, is wonderfully potent, but passed through the tissues of several text-books or handed down through several teachers, it is gradually weakened until finally when it is administered it is too weak to save us from the intellectual epidemics of the day.

CHAPTER I.

AN EPITOME OF THE HISTORY OF PHYSIOLOGY.

The word physiology now used to designate this and kindred subjects, has a very remote origin. Etymologically it means a discourse on nature, from the Greek words *physis* (φύσις), meaning nature, whence the word physical, and *logos* (λόγος), meaning a discourse. In this original sense it was employed by the earliest writers to include all the natural sciences. Soon astronomy was set off as a special science, and the term restricted to all subjects that deal with natural phenomena and natural objects close at hand. Little by little as human knowledge widened, and the accumulated observations and experiments in any one field became considerable, this field was separated from the general study of nature, physiology, and designated by its own peculiar name. In this way the accumulating facts in the domain of chemistry gave rise to the alchemy of the Middle Ages, and when later alchemy was stripped of its superstitions and fancies, it rose to the dignity of the science of chemistry. Soon purely physical facts were separated off as the science of natural philosophy and have become the science of physics. This eliminating process has continued with the progress of science until the original term physiology, which means the study of entire nature, has been contracted so as to apply only to that science which seeks to explain vital phenomena, be it in plant or in animal.

Etymologically physiology is the parent science and all others outgrowths of it. But not only in an etymological sense is physiology of early origin. While logically physiology follows physics, chemistry, botany and zoology, and

presupposes them at many steps, yet historically almost the exact opposite is true. It is a trait of the human mind apparently to attack a problem by attempting at once the explanation of its deepest questions. Thales, Anaximander, Anaximenes, Heraclitus and other early Grecian philosophers busied themselves with trying to explain the ultimate essence of things before the world had made even the first real attempt to learn something of the things themselves.

HIPPOCRATES.

Ancient writers cite Hippocrates of Macedon as the person in whom physiological observations began. He is often called the "Father of Medicine." Hippocrates was a contemporary of Socrates and Plato, and he is especially deserving of credit because he insisted that the proper way to study disease and health was by observation and experiment, and not by the application of general deductions. He antedated Bacon many centuries in trying to establish the inductive method of scientific investigation. While Hippocrates added but little to the physiological conceptions of his times, he described numerous phenomena with great care, and made observations and experiments which made him the foremost physician of his time. We still speak of the Hippocratic face after death, of the Hippocratic sleeve for straining syrups and decoctions, and in our drug stores may still be bought the wine of Hippocrates, supposed to be made after the formula of that early physician.

ARISTOTLE.

But while Hippocrates has possibly the honor of being the first scientific physician, the honor of being the first to study physiology scientifically belongs to Aristotle, often called the "Father of the Sciences." True it is that Aristotle laid down many of the fundamental conceptions of our sciences of to-day. One is astonished at his general knowledge, and in many cases the careful investigations of

later times have shown the accuracy of his observations on points which at first seemed mere fancies of his mind. He wrote several works on physiological matters. His works entitled, "Natural History of Animals," "On the Parts of Animals," on "Animal Locomotion," "On Respiration," are in part preserved, while a treatise on anatomy seems to have been lost. From these writings the views of his time are accessible. The main purpose with Aristotle was to explain the function of every part and organ described. Some of the main conceptions of Aristotle are here briefly given:—The heart is the central organ, and the motive power of the whole body. It is the seat of vitality, because it is the source of the animal heat of the body, all the warmth of the body being produced by the heart. The heart makes the blood, gives to it its *vital* stimulus, and then sends it all over the body through the blood vessels. The blood does not circulate, it never returns to the heart, but as fast as it is used up at the periphery of the body it is replaced in the heart. The blood is stored in the blood vessels as in a jar. Whence the name *blood vessel* used to this day. (The name "aorta" dates from Aristotle.) Aristotle describes the stomach and intestines, and hints at the proper conception of absorption. He describes the trachea by the name *artery*, and says that it carries air into the lungs. In the lungs the *spiritus* or *pneuma* is extracted from the air and by channels (pulmonary artery and veins, no doubt referred to) this "spirit" substance is carried to the heart, where it is mixed by the heart with the blood, and serves to give it its vital stimulus. The ancient notion that the air or "spiritus" is the vital principle still lingers in our everyday language when we refer to vital things as spiritual, or call the active element of wine spirits, although now having an entirely different meaning. Aristotle explains all vital processes as caused by *heat*. Heat was the "causa operandi" for everything. "Heat changes the metals, disintegrates ores, liquids, and then vaporizes ice, causes

the embryo to grow in the egg; in short, heat causes all the processes of life." "But this heat must not go too high, and so we have respiration, which enables us to breathe in cold air and so cool the blood. For this reason we breathe the faster the hotter we are!"

While much of Aristotle's information is remarkably exact when we remember his times, and shows him to have been a scientist such as the world has rarely seen since, yet here and there we find ideas that seem somewhat puerile. Thus he says with great earnestness "that in all his dissections, and he has made many, he has always found the windpipe leading to the lungs and the œsophagus to the stomach, nor has he ever found them interchanged."

PRAXAGORAS.

The views of Aristotle were extended by Praxagoras, whose important addition to physiological knowledge was the distinction he found between arteries and veins. He also noticed the pulsations of the arteries and the absence of a pulse from the veins. This was a material gain. But with this discovery there crept in a misconception which remained for centuries and formed the fundamental conception of all the earlier physiologists. This was that the veins are filled by, and carry the blood, but that the arteries have no liquid of any kind in them, but carry the mysterious "spiritus" or "pneuma," something akin but not exactly the same as ordinary air. This misconception arose no doubt from the observation that after death the arteries are empty and all the blood practically is found in the veins. The word artery, *arteria*, was used by Aristotle for the trachea, as it was clearly an air-tube, but was by Praxagoras applied to the pulsating blood-vessels under the idea that they too contained air. We still use the name artery, although since the time of Galen we know that they carry blood and not air. None of the works of Praxagoras are preserved, but his views are quoted by later writers.

HEROPHILUS AND THE ALEXANDRIANS.

Praxagoras had for his pupil the anatomist Herophilus, whose influence contributed to the renown of the school at Alexandria, whose greatest achievements were in the realm of anatomy, physiology and medicine. The great Alexandrian museum became the center of learning of the ancient world. Scholars from all parts of the world gathered there to prosecute their studies. The attendance is given by some writers as having reached 10,000 students at one time. A glance at some of the names will convince one of the pre-eminence of this first great university of the world. Here Euclid wrote his geometry, here Ptolemy worked out the "Ptolemaic" astronomy, Archimedes his physics. Here originated the theological disputes between Arius and Athanasius which culminated in the Nicene creed. Here the dissection of the human body was allowed by law, and the bodies of condemned criminals were turned over to the students of anatomy. Here the anatomists, Herophilus and Erasistratus, were the first "professors of anatomy" in a public institution. Many anatomical structures were here first described and still bear their ancient names, the tricuspid valves of the heart, the duodenum, the *calamus scriptorius*, etc. Erasistratus distinguished between connective tissue cords and true nerves, and even distinguished between sensory and motor nerves.

A marvelous advance was made by Herophilus in the conceptions of brain and spinal cord. By earlier writers they were regarded as unimportant collections of fat-like tissues something like the marrow of the bones. The fact that the earlier observers could see nothing in these structures except a soft structureless mass led to this error. The term "spinal marrow" still used is probably a relic of the times when this organ was not understood. Herophilus made the brain the seat of conscious activities; the center to which sensations are carried and the source of voluntary movements. What a step forward in the field of physiological research! But with all these advances they never

doubted the truth of the conceptions of Praxagoras regarding the arteries. They were in all calculations supposed to carry air or *spiritus*. This *spiritus* or *pneuma* they made the subject of many fanciful theories. It was still believed to be taken in by the breath and then carried to the heart, to be distributed by the arteries. It was the principle of life, and we have the ancient belief still illustrated in the familiar expression "the breath of life."

This *spiritus* by its vital energy caused the arteries to pulsate. Erasistratus carried this notion so far as to recognize two kinds of *spiritus*. One which was taken from the air is carried in the arteries and left side of heart, and the other a higher *spiritus* made from the first by the brain and stored in the ventricles of the brain (whence their use), from there to be distributed over the body by the nerves giving feeling and volition, while the part that remained in the brain became the bearer of consciousness and individuality. This was called the "psyche," a name retained to this day in such terms as psychical, psychology, etc., while we still speak of *animal spirits*, and sometimes hear of the nerves containing *nervous fluid*. Fever was believed to be due to the filling of the large arteries with blood and so interfering with the movements of the *pneuma*, while inflammation resulted when the blood was driven by the *pneuma* to the ends of the arteries, whence their distension. In a wound the artery contained blood, because as the air, or *pneuma*, leaked out and so caused a vacuum, blood soaked in to take its place. Normally blood was contained in veins only.

GALEN.

The physiology of the ancients reached its culminating point in the learned Galen, who practiced medicine in the city of Rome when the Eternal City had reached the zenith of its importance. He was a Grecian by birth and no doubt belonged to that class of Greeks which had been called to Rome to superintend the instruction of the imperial city.

Galen was the medical adviser of the imperial family itself and so probably the most learned physician of Rome. It is due to the genius of Galen to have put an end to some of the misconceptions clustering around the idea of the *pneuma* and the arteries. He established the fact that the *arteries normally contain blood*. He describes that having laid bare the axillary artery of an animal while it was pulsating regularly, and so according to the established notion containing *pneuma*, he pricked it with a fine needle, and found that in the very first instance blood came out, and not *pneuma*, followed later by blood, which had soaked in. When such a pulsating artery was cut the blood spurted out forcibly *at once*, showing that it must have contained blood before opening. What a simple and conclusive experiment! and yet it had taken the world centuries to think of it. He also described the heart very carefully, and even investigated successfully the changes in the circulation at birth, having found the *foramen ovale* and the *duct of Botallus* (*ductus arteriosus*), and noted the closing of the former and the atrophy of the latter. (See chapter on "Changes of the Circulation at Birth.") The discovery of the true blood-carrying function of the arteries was another tremendous step in the right direction, but in trying to work out his idea of the system of blood vessels Galen was led into several new misconceptions. From an historical standpoint, however, they are of peculiar interest. Galen made the liver the seat of the elaboration of the blood. The portal circulation carries the foods from the stomach and intestines to the liver (and in this he was correct) and by the liver this food material was transformed into blood. From the liver two vessels arose, one running downward to the lower part of the trunk, and lower extremities; the other running upward to the heart. (In this way he had interpreted the large *vena cava* running through the liver to the heart.) Through the right side of the heart the ascending vessel was extended to the head and upper part of the body (our descending *vena cava* and *innominate* veins) and

through the ventricle of the heart to the lungs (our pulmonary artery). This system he called the *venous system* and the blood venous blood. This venous blood was dark, being rich in nutritive matter and intended to give to all the organs to which it was distributed the proper substantial nourishing matters. On the left side of the heart and in the arteries there was an entirely different kind of blood, and having no connection in any way with the other or venous blood. This blood he termed the arterial blood. It was lighter in color and weight and carried the vitalizing *pneuma* dissolved in it which it received in the lungs. It also carried warmth to all parts of the body, which warmth was produced in the left side of the heart. Both kinds of blood ran to all organs, so that each organ could choose whether it wanted the nutritive, rich, thick, venous blood, or the quick, pulsating, active *pneuma*-containing arterial blood. It was still believed that the vitalizing influence now dissolved in the liquid blood, the *pneuma*, caused the properties of sensation and motion.

Galen, however, adds a new idea to explain the source of the arterial blood. The venous blood is elaborated from the food carried to the liver by the portal vein, but there seemed at first sight no way to account for the production of the lighter arterial blood. The vital spirits were extracted from the air and added to it in the lungs, from which place the blood carried the vital spirits to the left side of the heart, where the finishing touches were given to it, and from which it was sent out over the body. Galen solves this point by admitting that there are pores, very tiny ones though, through the thick ventricular septum, so that the finer parts of the blood from the right side could soak through these invisible openings to the left side. Further he contended, and this seems remarkable now, that the arteries and veins anastomose with each other at their outer ends by means of excessively fine sieve-like canals and pores, so that again some of the lighter parts of the venous blood could gradually soak into the arterial system, and so replenish the arterial

blood as it was used up. This view Galen supported by the observed fact that when an artery of an animal was cut, not only the arteries, but the veins, also, became emptied in a very short time.

Middle Ages.

With Galen the progress of the ancients in physiology comes to a close. A thousand years have elapsed before physiological phenomena receive the least attention, and nonsensical metaphysical debates on theological abstractions crowd out of the mind of the Middle Ages even the known conceptions of the past. Miracle cures replaced the medicines of Galen and Hippocrates, and superstition gave way to the anatomy of the ancients. More than ten centuries separate Galen from the first students of anatomy in the universities of Italy. But the Middle Ages had carried the seeds of physiology through these years of readjustment, and when the Italian Renaissance came, anatomical and physiological studies felt the mental awakening. For the first time in modern history, lectures on, and dissections of the human body formed a part of the regular program of studies of the universities. Mondini of Bologna, 1315, wrote a treatise on anatomy and dissection which remained the authorized text-book in most schools of medicine almost into the sixteenth century. Only twelve years after the invention of printing this treatise was printed in full, and by the year 1550 it had no less than thirteen editions.

The anatomy of the body is in many instances carefully described, and the chief value of the book is from an anatomical standpoint. In his physiological views the established notions are not questioned. During the Renaissance the works of the ancients were seen to be so much better than their present productions that practically implicit confidence was given to all things that had the authority of the past. Aristotle and Galen were not to be questioned, and it seemed senseless and unpardonable to try to

improve on what they said, and useless to try to add materially to their knowledge. Galen's views of the *vital spirits* and the circulation are accepted. Mondini adds his interpretation of the meaning of the auricles. They are to act as overflow reservoirs for the ventricles, to store the excess of blood or vital spirits when the ventricle is manufacturing these too rapidly.

Two hundred years later, in 1514, the chair of anatomy and physiology at Bologna was occupied by the surgeon, Carpi, who published a treatise on anatomy even more extensive than that of Mondini, but not differing from his predecessor in any of his fundamental physiological conceptions.

VESALIUS.

A new era in physiology was ushered in by the Dutch anatomist, Vesalius, 1537, whose immense credit lies not so much in what he himself contributed to the science of physiology as in the position he took with reference to the ideas of the past. He boldly antagonized many of Galen's views, showed that many of his observations had been conducted on animals and not on the human body itself, and so recognized the necessity for more definite descriptions. With Vesalius the absolute charm of the all-sufficiency of the past was broken, and he strongly suggested the necessity of beginning anew the investigations of anatomy and physiology, and the subjection of the ideas of the ancients to a careful and impartial test. He boldly denied that there are pores through the ventricular septum as Galen describes, and insisted that the traditional view of the blood circulation was wholly inadequate to explain all the facts, and he might have discovered the circulation of the blood had he remained the professor of anatomy at Padua and not been made court physician at Madrid.

SERVETUS.

The next great step forward in physiology came from an unexpected source and in a remarkable manner. The far-

reaching statement that *the blood passes from the right side of the heart through the lungs, and by means of anastomosing connections is transferred to the pulmonary vein and so returned to the left side of the heart*, was made by the Spanish theologian, Servetus. Servetus wrote a number of speculative treatises on theological disputes, which were condemned as heterodox by both the Catholic church and by Protestants. After the publication of his book, the *Errors of the Trinity*, he was obliged to leave his home, and under an assumed name entered the university of Paris, and studied medicine. But even in the field of medicine he was considered as little orthodox as he was in his theological views, and he was compelled to withdraw one of his medical publications by order of the Medical Council.

After drifting around for some time as a practicing physician he decided to publish a book which should set forth his theological views in detail. Soon afterwards appeared his book entitled, the *Restoration of Christianity*. In explaining in this book the workings of the Holy Spirit, he adds an exposition of the vital spirit of the human body. In this exposition he says that the blood *goes to the lungs from the right side of the heart, assumes a bright color in the lungs, and is then transferred to the pulmonary vein. Here it is mingled with the inspired air, is relieved of some waste products, and then returns to the heart, where the "vital spirit" is made out of the arterial blood.* Hence the soul resides in the blood and not in the solid organs. This soul is nourished from the inspired air and the finest constituents of the blood. "It, the soul, is a thin spirit elaborated by the power of heat, of a bright golden hue and fiery potency, containing in itself the substance of water, air and fire. The very mind itself, the highest form of the soul, resides in the choroid plexus of the ventricles of the brain. (The choroid plexus is a network of blood vessels lining the ventricles of the brain.) The hollow ventricles of the brain are to permit air to be drawn through the nose and ethmoid bone, and stored up in them,

so as to renew the spirit in the adjacent blood vessels and to ventilate the mind. However, in the abysses of these ventricles evil spirits often hide which make war upon our own spirit, and which are not put to flight until the assistance of the Holy Spirit is invoked. While consciousness resides in the choroid plexus, faith resides in the heart, because as faith is a fundamental virtue it resides where the vital spirit is originally made." Strange that with such a medley of beliefs, some of which seem to border on the blasphemous in their material conceptions of the Holy Spirit, there should be included in the plainest terms such a wonderful discovery as the circulation of the blood through the lungs. Servetus's book was at once seized as heretical, and poor Servetus, surrounded by all the copies of his book that could be found, was burned at the stake in 1553. Two of these original books still exist, one at Paris and the other at Vienna.

FABRICIUS.

The anatomists, Falloppius (whence the name Falloppian tubes), Botallus (duct of Botallus), Varolius (pons varolii), Eustachius (Eustachian tube), and others, whose names are familiar to us from anatomical structures that still bear their name, added to the science of anatomy rather than physiology. However, in 1574 another important step forward was made by Fabricius, in the remarkable discovery that the veins normally possess valves. As it was found that these valves all opened towards the heart, it seems almost impossible that Fabricius should not have stumbled upon the fact of the circulation of the blood as we know it to-day. But Fabricius made the blood flow from the heart outwards, against the valves, and he explained the valves, by saying that they prevented the too rapid flow from the heart to the organs. When there was danger of congesting the organs, the valves tended to close and so shut off more or less completely the supply of blood to that organ. The idea of the "vital spirits" taken in at the lungs was still unques-

tioned, but there was laid additional emphasis on the further idea that respiration was intended to cool or *refrigerate* the blood, and the increased breathing, following heavy exercise and the consequent rise in bodily temperature, seemed in this view amply explained.

Modern Physiology.

HARVEY.

The real Renaissance of physiology dates from the celebrated name of William Harvey, a lecturer in anatomy in the College of Physicians in London. To him we are indebted for the discovery of the circulation of the blood, as we now understand it. With this discovery a myriad of older conceptions were forever swept away, and the foundation laid for a real scientific study of physiological phenomena. Harvey was convinced that the older views concerning the heart were wrong. He was an indefatigable experimenter, and was sure from his observations on the living heart that it was nothing more than a pump. He showed that the veins carried blood to the heart, for when he tied the veins the portion next the heart became empty and soon the heart itself was empty, while the vein beyond the ligature was distended with accumulating blood. As soon as he removed the ligature from the veins the distended portions emptied themselves, the veins became filled near the heart, and the heart itself was distended. If, on the other hand, he ligatured an artery the portion next to the heart became largely swollen, the blood was gorged in the distended heart, while the artery away from the ligature gradually emptied itself. Now, when the ligature was removed the heart emptied the blood into the relieved artery at once. Nothing could be clearer. Harvey explained the function of auricles and fairly accurately described the phenomena of the heart's beat.

This remarkable discovery was published in the year 1628, which date may be considered the beginning of Modern physiology, and the close of its "Middle Ages." The

book was written in Latin, as was usual in those times, and is called *Exercitatio Anatomica de Motui Cordis et Sanguinis in Animalibus*. A copy of this original edition is now in the Astor Library in New York. It seems curious, however, that Harvey should not have believed in a direct anastomosing of the arteries and veins. Such a notion had been advanced by former anatomists, and it seems but natural that Harvey should at once have accepted this view to explain the translation of the blood from the arteries to the veins, the only missing point to establish his discovery. Just how the translation is effected Harvey was unable to answer.

Harvey's discovery made a profound impression upon the thinkers of his day. It was a revolution in the accepted doctrines of more than 2,000 years. It did away with the somewhat fascinating "vital spirits," with the "moving force" inherent in "arterial blood," and with the mystic functions ascribed to the heart and lungs. It made the heart a mere muscular pump, it explained all the valves of the heart and veins simply as those of an ordinary water pump, it explained the mysterious pulse as a mere wave caused by the contraction of the heart forcing the inert blood into the arteries, just as would have occurred if water instead of blood had been used. It did away with the idea of two kinds of blood, venous and arterial, and showed that one was changed into the other in the lung by being put in contact with the air. Men are always slow to part with ideas that have the prestige of the past, and so we find Harvey's views at once stubbornly opposed. The learned physician, James Primerose, wrote a lengthy treatise opposing Harvey's views in which he criticises Harvey very severely for taking "too great license in impugning the doctrine of the ancients."

LATER INVESTIGATORS.

Harvey's experiments were, however, so convincing that it was useless to question them, but the authority of Galen

was still too strong and several attempts were made to adapt the views of Harvey to the conceptions of Galen. Riolan, the anatomist of the celebrated Paris School, published his *Circulation of the Blood*, 1648, in which he tried to show that Galen was correct in the main, but that a little, just a little blood circulated from the arteries through to the veins. It did not, however, circulate through the lungs, but the venous blood reached the arteries by passing through the ventricular septum. The lung was to furnish the "vital spirits" as before understood.

Gradually Harvey's views were adopted, and a new epoch in physiology ushered in. In 1651 Bartholini and Rudbeck announced the discovery of the system of lymphatics, thus adding another chapter to the circulation, and in 1655 the circulation of blood was finally demonstrated as a fact by Marchetti of the University of Padua, who injected a human cadaver and was thus enabled to follow the translation of the injected fluid through the entire circulation.

The capstone of the fact of the circulation was finally added by the celebrated physiologist Malpighi, of the University of Bologna, 1661. It was he who saw for the first time the circulation through the capillaries. He examined with a "magnifier" the lung tissues of a frog, and to his surprise found the long disputed connections between the arteries and the veins. The discovery and description of the "plexus of capillaries" belong to Malpighi. Soon afterwards with the just-invented microscope, Leeuwenhoek of Holland, the pioneer in microscopy, discovered the "red globules" circulating in the blood. By this chain of discoveries was established one of the most important chapters in physiology—the circulation of the blood.

A long line of illustrious physiologists has contributed its discoveries from that time to the present. The phenomena of respiration were cleared up when Priestly and Lavoisier discovered oxygen gas and explained the nature of oxidation. Priestly and Lavoisier were misled, however, in believing that the lung was the seat of the oxidation in the body,

and that the heat made here was carried over the body by the blood. The important fact that the oxidation is in the tissues themselves was finally established by Liebig and Pflüger in their study of muscular tissue in 1867. The nervous control and regulation of breathing studied first by Le Gallois in 1812 was extended by Flourens in 1842, Traube 1847, and Rosenthal 1862. The processes of secretion were also soon investigated. The notions of the ancients on this point were very primitive. They regarded the discharge of the mucous phlegm from the nose as an elimination from the brain which soaked through the ethmoid bone into the nose. The study of glands by Peyer, Brunner and Malpighi soon established the anatomy of secretory tissues. The action of nerves on glands was brought to light by the successful experiments of Ludwig and Bernard of our own day, who succeeded in producing the salivary secretion by the artificial stimulation of the nerves going to the gland. The celebrated physiologist of Berlin, Du Bois Reymond, brought to light a multitude of observations on the electrical properties of living tissues. To that most remarkable scientist, Helmholtz, of Berlin, we are indebted largely for the accurate knowledge we now possess of the physiology of the eye and the ear. The Young-Helmholtz theory of color is still the best interpretation of color sensations, and the studies in the physics of harmony have solved for us to a very large extent the problem of the ear. When to this is added the measuring of the rate of transmission of nervous impulses and the exposition of the law of the conservation of energy, it will be seen how much has been added by this scholar.

The history of special problems in physiology will be found noted in their respective places in the book. It is hoped that the foregoing epitome may show the interested reader the long road by which our familiar ideas have reached us. It is believed that a clearer perception of the efforts and the struggles which it has cost great men to interpret for us these phenomena may result in a quickened

appreciation of their labors. It finally justifies us in the belief that the future will contribute to the science of physiology as much as the past has done, and that many problems which are still almost wholly unsolved may be rapidly nearing their solution.

CHAPTER II.

THE CELL AND ITS LIFE.

Probably the most fundamental conception in biology is that of the cellular structure of all animals and plants. The discovery that all living things are made up of separate and individual cells laid the scientific foundation for the sciences of histology and embryology, and very materially modified physiological investigation. It is the bridge that connects plants and animals, and is the key to the proper understanding of the phenomena of their growth and development. But such a far-reaching and clarifying conception did not appear suddenly. Our present notions are the result of much investigation and reach back through the observations of many years. The ease and familiarity with which we now speak of cells, of protoplasm, of nucleus, etc., might argue at first sight that we are dealing with a long established, always-evident bit of knowledge, while as a matter of fact these ideas are even now in the process of formation.

HISTORICAL VIEW.

When Leeuwenhoek, the pioneer in the use of the microscope, began to extend human observations with the aid of this added sight a new world was opened, and with avidity, sometimes with mere curiosity, observers subjected all sorts of things to the scrutiny of the microscope. In this way Robert Hooke, of England, 1667, while examining somewhat indiscriminately all sorts of things with his rude microscope, placed a thin section of ordinary cork under the instrument and noticed that the section contained innumerable little chambers which, because of this, he called *cells*. He had, of course, no idea as to the meaning of these chambers, but used the term "cell" as we still employ the word

nowadays when speaking of the chamber of a prison as a *cell*. Although Hooke's notion regarding these chambers or cells has long since been changed, the term he applied to them has remained, and there is little probability that it will ever be displaced, so firmly is it established in biological science.

Fig. 1.—A SECTION OF WOOD SHOWING THE CHAMBERED APPEARANCE.

Fig. 2.—CELLS IN GROWING WOOD.

Several years later (in 1671) Malpighi and Grew each published a treatise on structural botany in which this chambered or cellular appearance was noted as occurring in many other vegetable tissues besides cork. For more than a century nothing further was done, and it was not till the beginning of our own century that the observations in this direction were renewed. In 1812 Moldenhauer, a Dutch scientist, by macerating plant tissues succeeded in isolating individual cells. (Experiment easily repeated with a ripe, mealy apple.) This changed the idea of Hooke that cells were but empty chambers in a homogeneous mass, to the correct view that cells are individual structures having a solid wall enclosing the chamber. In this way the cell wall and not the empty space seemed to be the essential thing. Soon after this, however, Corti and Amici found that many cells are filled with a liquid *sap*, and in several instances they had observed this sap circulating in the cell without being affected by an external power. Such further observations emboldened Meyen, in 1838, to venture the assertion that a part of the cell sap must surely be *alive*.

In the meantime Robert Brown, 1831, had discovered the nucleus inside the cell. Thus little by little the contents were considered as the essential thing of the cell, rather than the cell wall. To help this view the botanist, Unger, in 1843 made a series of discoveries of a then astounding character. In examining the green scum everywhere plentiful on moist flower pots (*vaucheria*), he saw the cell sap "crawl" out of the old cell wall and creep away. This is the common phenomenon of rejuvenescence easily observed, in which the protoplasm leaving the old cell wall becomes active for a while, and then produces a new *vaucheria* thread. But to Unger it was a plain case of the sap of a plant cell turning into an animal. The misinterpretation was strengthened when soon afterwards Kritzinger observed green amœboid cells changing into filaments of *algæ*. Here was a case of an animal changing to a plant. But it established one thing as correct—that the cell contents are the essential thing and the cell wall quite secondary. To the mysterious contents endowed seemingly with vital properties, Hugo von Mohl in 1846 gave the name *protoplasm*.

All these views were then moulded into a definite theory by Schleiden in 1849. It will be observed that up to this time all the observations had been confined to plants, but in 1849 the histologist, Schwann, showed that animals, too, are made up of cells, and applied the cell theory equally to them. The theory was therefore called the "Schleiden and

Fig. 3.—CELLS FROM THE ANIMAL BODY (CORNEA). (After Schäfer.)
c, columnar cells; p, polygonal cells; f, flattened cells.

Schwann cell theory." The manner in which these cells

originated was not known, although the current notion was that new cells arose "in between" old cells. That a tiny granule, the nucleus, was in some manner deposited between already formed cells, and that around this nucleus the rest of the cell gradually arose by a process of precipitation like the growth of a crystal in a supersaturated solution of that substance. How inconsistent that view was with all the facts of heredity seemed not to be considered.

The remarkable advance in knowledge, that a new cell arises only by a division of a pre-existing cell is due to the botanist Nägeli, who had observed this manner of cell production. And when finally Max Schultze in our own day proved the identity of protoplasm, whether taken from plant or animal, the cell theory as we now understand it, was in its general outlines established. Added proof was further given to this theory (now really a fact) when Dujardin and Haeckel showed that many of the lowest animal and plant forms were in reality nothing more than single cells.

A TYPICAL CELL.

As the cell figures so prominently in the proper understanding of nearly all histological structures and throws so much light on physiological properties and the problems of heredity, a more general account of it is here given as an introduction to the histological matter further on. A typical cell consists of a mass of *protoplasm* surrounded by a *cell wall*, and containing within it a *nucleus*. *Food material* also frequently occurs diffused through the protoplasm. Recently there was discovered a further structure, lying usually close to the nucleus, the *centrosome*. The exact nature of this body is not yet fully established, but it seems to play a very important part in the division of the cell. The nucleus is made up of a substance which stains deeply when treated with the usual staining agents and has been called *chromatin*. The nucleus is that part of the cell which seems to influence and determine the function of the cell, and from the important role it plays in

Fig. 4.—AMOEBA. (After Leidy.)

n, nucleus; *cv*, contractile vacuole (excretory organ); *N*, food vacuoles; *ek*, exoplasm; *en*, endoplasm.

Fig. 5.—A TYPICAL CELL FROM THE INTESTINAL EPITHELIUM OF A WORM. (Carnoy.)

mc, membrane of cell; *pc*, protoplasm of the cell; *mn*, membrane of nucleus; *pn*, achromatin of the nucleus; *bn*, the chromatin filament about to change into the separate chromosomes.

the formation of a new cell, is believed to be the carrier of those qualities and properties which we are wont to designate as those of heredity. In cells which have lost the power of division the nucleus practically disappears, but it is conspicuous in eggs which are about to usher in a period of active cell division. By a chemical modification of the protoplasm of the cell, the cell is differentiated into the required tissue in question. By changes of some kind in the protoplasm of the cells are brought about all those phenomena of physiology such as *secretion*, *absorption*, *assimilation*, *contraction*, and some physiologists go on to add—*consciousness* and *thought*, a step by no means yet fully warranted.

These various activities of the cells will be discussed in their appropriate chapters, and attention is called here briefly only to the somewhat complicated, but interesting process of the indirect division of the cell.

THE DIVISION OF THE CELL.

When the process of cell division, called *karyokinesis*, is about to be ushered in, the centrosome lying close to the

nucleus is seen to divide, and the two parts move toward the opposite ends or poles of the cell. Just what these centrosomes are is still an unsettled question. Radiating from these centrosomes there soon appear little delicate threads, believed by some observers to have been derived from the achromatin of the nucleus; by others, from the protoplasm of the cell body. The threads between the centrosomes seem to be continuous, that is, extending from one centrosome to the other, and thus forming a so-called "spindle." The continuity of these threads is questioned by others, who believe that they extend no further than the "equatorial plate." In the meantime the nucleus undergoes changes by which the chromatin of the nucleus appears as a more or less coiled thread, which soon breaks up into a number of V-shaped loops called chromosomes. The number of these chromosomes varies for the different species of animals or plants, but in the same species it is practically constant. These chromosomes arrange themselves in the region of the "equatorial plate." A longitudinal splitting of each chromosome doubles the original number of V's. Half of the V's now move toward the one pole, the other half to the opposite pole. Whether the spindle threads serve in any way to draw or guide the individual V's is an interesting but unsolved question. When the chromosomes have arrived at their destination the individual V's again fuse together, and soon two nuclei have replaced the original one. The cell protoplasm now seems to arrange itself with reference to the two new nuclei, and a constriction of the old cell wall, or the formation of a new wall along the line of the equatorial plate finally produces two separate and distinct cells, which in turn, by repeating this same process, may produce two more, etc. The extreme care in dividing the nucleus (which is the bearer of heredity) shows that nature takes every precaution to give to each daughter-cell an exact proportion of all those attributes which heredity passes from one generation of cells or individuals to the next.

Fig. 6.—SHOWING SOME OF THE STAGES IN THE DIVISION OF THE CELL.

It is interesting to observe that simple animals, who in comparison with the mammals, say, have but little that is passed on to the succeeding form, show a much simpler type of cell division. When we remember that in the chromosomes of the egg there are housed in their finer structure those determining influences which later on will reappear in the shape, size, structure, coloration, intonation of voice, and even instincts of a wonderfully complicated adult individual, we are not surprised to see the care with which the chromosomes are elaborated, for the important purpose of producing a new cell. While it explains in no sense the real cause of heredity, it is apparent that in this process there is a valuable suggestion as to the actuality of a physical basis for heredity.

CHAPTER III.

THE TEACHING OF PHYSIOLOGY AND THE PUBLIC HEALTH.

No one will question the validity and appropriateness of hygienic considerations in a treatise on physiology. To promote the individual and the general health are the purposes assigned to physiology by the law which made it a common school subject. While, of course, there is danger of materially destroying the educational value of physiology by having it degenerate into a dried and cut code of empirical formulæ, mostly without any real practical value; while the ordinary school often sins by spending valuable time in giving platitudinous advice which it was never the intention to have followed to the letter, there is, on the other hand, the possibility of repaying a thousand-fold the money and time expended in teaching physiology if there could be put into the practical belief of all its students a clear perception of the fundamental laws that govern proper sanitation and of the scientific methods of preventing disease. To be obliged to acknowledge, as true it is, that most of the diseases of the human body are due to agencies which it is entirely possible to control, and even eradicate, by properly directed sanitary and hygienic methods, shows how urgent is the necessity of impressing this information upon the attention of the public at large.

In a perfectly healthy community, possessed of a perfect system of sanitation and barring the direct introduction of disease by admitting affected persons from the outside, the infectious and contagious diseases would and could never appear. Diphtheria and scarlet fever would leave children untouched, and consumption and typhoid would disappear from the lists of mortality. It is, however, use-

less to effect sanitary reforms by the *ipse dixit* of the law. The efficiency of a law is directly proportional to the number of people who thoroughly believe in its provisions, and a widely disseminated knowledge of the conditions of health and disease must precede the statutory enactment of sanitary laws. Our national health must depend upon the education of the masses in this direction, for repeated systematic attempts by some of our cities to force people into cleanliness and virtue by police regulations have proved how fruitless such procedures are in the end. The public at large is too conservative in its modes of thinking, to fully acknowledge the value of these proposed hygienic reforms, for the notion that nearly all disease is due to a violation by us of some sanitary law is too recent to be fairly established in the public mind. The wonderful insight into the nature of contagious diseases and their prevention is almost wholly a product of the present decade.

HISTORY OF SANITATION.

But it must not be assumed that the value of sanitary precautions was not appreciated at all in former times, for the injunctions and directions of the Mosaic code were but the attempts of the Jews to tabulate what experience had proved to them to be valuable in preserving their national life. Their regulations with reference to their food, and their treatment of lepers clearly instance this point. The observance of this code is no doubt one of the causes of the persistence of the Jewish nation through historic time, and explained the comparative immunity of the Jews from the epidemics of the Middle Ages. The cruel and hard, but terribly effective code of Lycurgus for the Greeks had not a little to do with the production of the manhood of early Greece, and the abandonment of this code by the later Greeks was one of the elements that contributed to their national decay.

The Romans also appreciated the value of proper drainage, and the Cloaca Maxima of Rome stands as a monument

to this day to that effect. The remains of the aqueducts around Rome show on what a stupendous scale the city was furnished with pure drinking water. On the other hand, history plainly tells us that the wanton violation of physiological laws by the pleasure-loving Romans of later days, together with the epidemics that repeatedly devastated the Imperial city, had much to do with the decline and fall of the empire.

It is, however, in the Middle Ages that we see the most flagrant violations of the laws of health. The clothing of the people was made almost entirely of wool, and little suited to the varying temperatures. The dwelling houses were of the rudest construction; and clean floors were unknown. New straw was placed from time to time upon the floors of dwellings to cover up the filth that had accumulated there. A writer of this period states that whenever he went into a house of this kind he was immediately seized with a fever. Strong ale and sour wine, usually drunk to excess, were prolific sources of disease, and highly seasoned and salted meats formed the substance of the daily diet. Streets were unpaved, and almost to the close of the Middle Ages the man who would have started to walk down the streets of Paris itself on a rainy day would have stepped into mud up to his ankles. Sewers were unknown, and the filth and garbage were turned over to the slow process of decomposition in their very midst.

When one remembers that there was constant fighting, that people were crowded in walled fortresses and towns without pure air, and finally adds that the country was filled with murderers, marauders and thieves, with frequent famines to augment this class, one can appreciate what was meant by Darwin's notion of the "survival of the fittest." Only the strongest and heartiest survived; the weak went to the wall. It was an illustration of Darwin's law with barbarous reality. But it gave to the modern age a picked race of stronger and heartier people. One is not surprised that under such conditions epidemics were plentiful and

famines frequent. Thus, in the twelfth century there are recorded fifteen general epidemics; in the thirteenth century, twenty general epidemics; in the fourteenth century, eight. It was in 1348 that Europe was devastated with the epidemic called "The Black Death," or "The Great Mortality." In London, alone, 100,000 people were carried away, and it is estimated that on the continent of Europe not less than one-fourth of the population, that is, more than 25,000,000 of people, fell prey to its ravages. The imagination of to-day fails to picture the horror and black despair of the time. Throughout all this period epidemics were believed to be visitations from an angry God, and there were not missing observations of armies fighting in the air, and other supernatural phenomena which served as warnings and forerunners of these dread times.

With the middle of the seventeenth century there dawned a better day. Improved methods of agriculture and commerce materially bettered the daily food of the people. The introduction of tea and coffee replaced the baneful effects of strong ale and spirits; and the introduction of the potato displaced the highly seasoned meats. Cotton and linen goods were revolutionizing clothing. But possibly the greatest advance of all was the discovery of soap. With the introduction of this now indispensable article the reign of filth and uncleanness began to weaken. More and more general attempts at municipal cleanliness resulted, and it began to dawn in the minds of men that disease and filth had a causal connection. Men learned for the first time that the prevention of disease might be investigated as a scientific problem. Several remarkable discoveries about this time helped materially in the sanitary evolution of civilization at large. One of these was the discovery of Captain Cook that that dread disease, scurvy, might be entirely prevented. This disease had for centuries decimated the ranks of soldiers and sailors, and was the especial dread of every ship's crew. The simple

addition of lime juice to the food of every sea-going vessel precluded the possibility of this sickness.

Another cause of great mortality was repeated outbreaks of jail fever in the prisons of the country. This disease was frequently carried from the prisons to the outer world. It was later recognized as the typhus fever of to-day. It was due to the careful observation of John Howard that this disease was traced to filth and overcrowding. Reforms based upon this have made jails healthier than many homes, and this disease one of the rarest occurrence.

Then, in 1796, came the discovery of Edward Jenner that smallpox might be prevented by the process of vaccination. While the absolute validity of vaccination is still questioned by some people to-day, there is no doubt about the fact that the mortality due to this disease has been many times reduced by this process.

THE SCIENCE OF BACTERIOLOGY.

It was reserved to our own day to give us a scientific insight into the cause of disease. The science of bacteriology is a product of the last few years. At first a small branch of the science of botany, bacteriology has commanded more and more attention; has ramified in wider and wider directions until now it has the dignity of a distinct science; and there are perhaps few subjects of study which are to-day being pursued with such an avidity, and in which the results obtained have proved of such unspeakable worth. An elementary understanding of the more important conceptions of bacteriology is necessary to a proper appreciation of hygienic laws. No one any longer questions the cause of all our contagious and infectious diseases. It is a matter of every-day comment to speak of the various germs producing respectively the various contagious diseases. A short summary of the growth of this science may be a matter of interest.

BACTERIA.

Very tiny living objects, visible only with the higher power of the microscope, had frequently been observed by botanists and zoologists. Their almost universal distribution had been commented upon. Attempts were made to properly classify them in the system of nature. At first regarded as animals, they have finally been relegated to the domain of botanists, and are now viewed as belonging to the plant kingdom. But little attention was paid to them until the remarkable observation was made that there seemed to be a causal connection between such micro-organisms and certain known diseases. It is due to the genius of the Frenchmen Davaine, Pasteur and Chauveau to have given us the germ theory of disease, our notions of fermentation, and the first successful attempts at protective inoculation. The first disease that was clearly proved to be due to such organisms was the splenic fever, which about the middle of this century was playing such havoc with the sheep and cattle of the continent. Beyond the peradventure of a doubt it was shown by these Frenchmen that these little germs not only caused the disease in the animals studied, but that such germs might actually be taken into the system of other animals, and so produce the disease anew.

A wonderful addition to our knowledge was made in 1872, when Klebs explained the phenomena of the inflammation of wounds and blood poisoning. He had occasion to examine numerous wounded soldiers of the Franco-Prussian war, and observed that in the wounds and abscesses of such individuals there were always found such organisms, and he proved that even deeper portions of the body to which the inflammation had extended had been so diseased by the migration of these micro-organisms along channels that he was able to trace. Few discoveries have done so much to alleviate human suffering and to lessen the dangers of surgical operations as this knowledge that

inflammation is due to the introduction of a foreign organism. And when finally the celebrated Lister, of England, perfected his methods of antiseptics in surgery, the scientific basis was laid for present surgical skill. Only three years later, in 1875, Klebs succeeded in finding the bacillus of diphtheria.

Then what a contribution it was to medical knowledge when the German bacteriologist, Koch, in 1882, published his preliminary article in which he proved that that dread disease, consumption, was caused by such a micro-organism! Discovery followed discovery, and in the space of but a few years the germs which cause cholera, hydrophobia, lockjaw, leprosy, malaria, typhoid, and other fevers were discovered. With this discovery it was possible to make experiments with a view of preventing these diseases. It was possible to work out the life-history of the germ—under what conditions it would grow best; under what conditions it would be retarded in its growth; what agency would suffice to destroy it; in what manner it could be carried from place to place; through what avenues it reached the body. This explained at once how garbage and filth of any kind were a prolific source of disease. This explained general epidemics, but it also suggested efficient ways of protection. The sterilizing action of heat was clear, and the use of antiseptics was susceptible of everybody's understanding. To show what a clear insight it gave into diseases previously not at all understood, common malarial fever may be taken as an illustration.

No one could explain why a patient should every third or fourth day be seized with a fever paroxysm and be comparatively free from the disease during the intervening period. No hint was obtainable anywhere. What was its immediate cause? Bacteriology has revealed that this common ailment is due to a tiny organism (sporozoa) which lives as a parasite in the red corpuscle of human blood. Introduced into the blood from various poorly drained areas containing much decayed organic matter, it finally finds

lodgment in the corpuscles. The corpuscle containing this parasite loses its vital properties, is robbed of its coloring matter, the hæmoglobin, and so materially reduces the efficiency of the blood to nourish the body. Two kinds of parasites have been found which differ from one another in the time required for producing new spores. In one species each parasite produces a brood of new spores every third day. In the second parasite the new brood arises every fourth day. It is the formation of this new brood of spores every third or fourth day which causes the malarial paroxysm, probably because in the formation of the spores some poisonous substance is eliminated. If, as it often happens, the patient houses in his blood two sets of these parasites whose times of spore formation varies, the paroxysms vary accordingly, and so explain why the chill may recur on successive days, then miss a day only to recur again on the fourth day. We understand how the destruction of the red corpuscles of the blood by these infesting parasites will produce the anæmia, so characteristic of malarial fever.

The germ of the only too prevalent typhoid fever we can now produce in pure cultures in the laboratory test tube. We can see how it thrives and multiplies in decaying organic matter. It can easily be observed what a healthy medium sewage water is, and we can follow through all its vicissitudes this agent of mortality. Bacteriology answers satisfactorily the prevalence of consumption, the agent that carries off more victims than probably any half dozen other diseases combined. Nuttall, of Johns Hopkins Hospital, in making quite a number of careful calculations found that a patient only moderately advanced in the disease eliminated from his body in the sputum during a short period of twenty-four hours, from one and one-half, to four and one-third *billions* of bacteria. These billions form part of the dust which by the winds is spread broadcast and carries infection to the first susceptible lung, or washed away by the rains finally finds its way back through drinking water

to some person, there to set going the various forms of gastric or intestinal tuberculosis.

In such a brief account we are not specially concerned with the question what bacteria are. Suffice it to say that they are minute organisms, among the smallest known. Several typical forms are usually described. Thus the little round globular form, such as the germ that causes erysipelas, is called *micro-coccus*. The short rod-like form, such as the one that induces the decomposition of flesh, is called *bacterium*. (Used in this instance in a special way and not referring to the whole group.) Longer rod-like forms are represented by the germs of consumption, typhoid fever, leprosy, lockjaw, etc., and are called *bacilli*. The comma bacillus of Asiatic cholera has a slightly bent shape not unlike the comma, whence its name, and belongs to the order of the *vibrios*. In typhus recurrent fever occurs the cork-screw-like form called *spiro-chaeta*, while the undulating snake-like form frequently found in the mouth and the teeth, is called *spirillum*. In addition to the active forms most bacteria are able to produce, when the necessity arises, spores which are able to resist drought or any other unfavorable circumstance for a long time, only to germinate again as soon as proper conditions arise. The resistance of some of these spores is almost incredible. The spores of the hay bacillus, found in ordinary hay, may be boiled several minutes without injuring their vitality. Spores may be formed either by the protoplasm of a bacterium forming a thick wall around itself for extra protection, or by the protoplasmic contents of a bacillus splitting up into several small globular bodies which are soon provided with a thick coat, and in this form mingle with the dust of the atmosphere to be wafted and scattered by every breeze that stirs.

But it must not be supposed that all germs are disease-producing. Many of them are of the utmost benefit to us. The germs that cause the ordinary decomposition of organic matter by returning it to the elements, keep things clean

and pure, while the bacteria which are found in such great numbers in the soil act as a biological filter, destroying all the impurities so that the water at a reasonable depth is entirely free from organic particles. The very plants are dependent upon the bacteria of the soil for their nitrogenous food. Botanists assure us that were it not for the nitrification caused by the bacteria in the ground the entire plant world would be reduced to a stunted growth. The very processes of digestion in the human body are helped along by bacteria which live normally in the human intestine, and some of the most extensive commercial enterprises are dependent upon fermentations brought about by the aid of these small organisms.

HOW GERMS PRODUCE DISEASE.

The question naturally arises, just in what manner these bacteria produce their respective diseases in the body. Is it due to the depredations of the bacteria themselves, or some product which they produce while in the body? No one will question the fact that much harm results from the actual destruction of tissues literally eaten up by these germs. The gradual disintegration of the consumptive lung is more than sufficient evidence, but it is now generally conceded that the injurious effects of these bacteria are due to poisons which they elaborate in the body rather than to their own immediate presence. These poisons directly attack the tissues, and to their effect are due the symptoms of the disease. It has been possible to extract these poisons from animals afflicted with certain diseases and then to inject this poison, free from the bacteria which produced it, into healthy animals, there to reproduce all the symptoms of the disease in question. It is probable that these poisons are similar to the alkaloids of the organic chemist.

THEORIES OF IMMUNITY.

The explanation of the fact that the first attack of many infectious diseases renders the person immune from a

succeeding one is not yet at hand. A number of interesting theories have been advanced to account for this immunity. Pasteur held that there was a special food in the body which these bacteria needed and which was completely used up in the first attack, thus making the second one impossible; but as the blood changes in composition so rapidly it seems impossible that such elements would not again soon be introduced if they were normally in the blood. Then Chauveau ventured the opinion that these germs produce excretions which finally render the blood unfit for them to live in and thus prevent the recurrence of the disease. When we remember how quickly the system normally throws off foreign poisons it seems hardly possible that the body should retain these excretions for such a long time as the immunity seems to last. Later, Grawitz proposed the idea that the outcome of a disease was the outcome of the battle waged between the bacteria in our bodies and the living tissues, that if the tissues managed to obtain the upper hand and destroy the bacteria the training so acquired would increase their *vital energy* and *resisting power* and so cut short a second attack, something as a regiment of veterans would be less easily overcome in battle than a corps of raw recruits. Succeeding this Buchner gave as his explanation that in a first attack the places at which the bacteria were introduced became more resistant and so prevented the introduction of succeeding ones. This went on the supposition that all kinds of bacteria had their specific places through which alone they could enter the body. It is not necessary to state that this explanation found little support.

Then came the now celebrated theory of Metchnikoff, which holds that the white corpuscles of the blood and lymph are scavengers going up and down between the tissues, and picking up foreign particles wherever found. This picking up is nothing more than the process of amœboid digestion. This theory is now very generally accepted, and observations clearly show that these corpuscles do take

into themselves under some circumstances foreign particles. Thus if a pus cell from a wound be examined it is usually found to contain many foreign particles, usually bacteria. The corpuscles with their load of included bacteria are then probably sent to the spleen or liver, there disintegrated, and the injurious products eliminated from the body in accordance with the regular physiological process. This theory explains in a very interesting way the phenomena of the inflammation of wounds and the gathering of sores. In a wound such as an open cut the bacteria of the air fall at the first exposure and there in the rich nutritious blood begin a course of active development. Soon, however, white corpuscles congregate around the wound, the blood usually following through the openings in the capillaries caused by their migrations, hence the redness. These corpuscles move regularly towards the infected center, removing the germs as they progress, until finally all of the corpuscles with their incepted germs meet in the center of the wound there to be, possibly mechanically, pressed out as pus. It is known that wounds entirely protected from germ contamination will not inflame at all, and surgical operations of the most violent character with modern antiseptic improvements may be carried out without any appreciable amount of inflammation. Possibly the added vitality that is supposed to come to these amœboid cells in their first successful battle enables them to cut a second venture short. That these corpuscles are concerned in the elimination of foreign particles from the blood is probably above question, but that this explains all the phenomena of immunity is another matter.

The most recent view and possibly the best substantiated one of all is the acclimatization theory, which tries to explain that we are immune from a second attack by having become accustomed or acclimated to the poisons in the first attack. To use a not very elegant analogy, it is like the boy who can smoke his second cigar without getting sick, because he has been somewhat hardened by the first

one, and possibly the best preparation of a person who is to be treated to a terrific dose of nicotine would be to gradually more and more accustom himself to the injurious effects of that alkaloid.

Just what may be accomplished by gradually inuring the body to poisons is remarkable. By slowly increasing doses, strychnine may finally be given in amounts so large that they would have produced instant death if administered for the first time. Arsenic eaters are able to take amounts of that drug which would be out of the question by one who had never taken it before. Possibly this view explains the philosophy of vaccination and anti-toxine methods. As every one knows vaccination for smallpox consists in introducing a weakened form of that virus into the body which there produces a mild attack of smallpox. In this attack the poison is developed so slowly and gradually that the body can adjust itself to these increasing amounts and a succeeding attack of the violent form, would thus not be able to strike down the energies of the body at the very onset before possibly the body had had time to overcome the dangerous intruder. In the anti-toxine method now used in diphtheria the serum of a horse which has had diphtheria, and in which blood, therefore, is found some of this diphtheretic poison, is injected in small doses into the body of the patient suspected of developing diphtheria. The poison so injected in small, or slightly increasing doses gradually allows the body to adjust itself to it so that later on when the disease has produced greater quantities of this same poison the tissues have been acclimated to it to such an extent that the poison does not prove fatal. As the bacteria themselves can not live when the amount of the poison which they have formed becomes too great it may be too, that the introduction of some of this poison into a patient's blood will serve to check the growth of the microbes.

UNSOLVED PROBLEMS.

The specific germs of measles, yellow fever, and even smallpox itself are not yet definitely known, but from the

success bacteriologists have had in studying other infectious diseases we may reasonably expect light on these points in the not very remote future.

PRACTICAL GUIDANCE.

It was not the province of this chapter to discuss at any length bacteriological problems. Its purpose was to call attention to a few scientific facts which should form the basis for a sensible appreciation of sanitary and hygienic laws; and when we remember that most people die with some form of infectious or contagious disease, surely no excuse is needed to press such information upon the attention of the common-school teacher who has the greatest opportunities for distributing it. It is intended that the few points here given shall lead to such a general and interested observance of all rules and regulations to advance the general health, that disease may become more infrequent, and the length of human life and happiness thereby materially increased. Possibly nothing better can be done in this case than to quote here the rules and regulations recently issued by the Indiana State Board of Health, which are so clear and to the point that they are given without further comment:

Explanation.

“Simultaneously with the annual opening of the public schools, diphtheria, measles, mumps, scarlet fever and many other diseases usually increase. This is caused by the congregating of the pupils. They mass together and contact spreads infection. Some few pupils may have just recovered from a communicable disease, or they may be from families that have been smitten, and, being infected, they transmit disease to those who are susceptible. It is reasonable to assume that the suddenly imposed confinement in the schools after a period of freedom frets the children for a few days, causing more or less nervousness and so resistance is temporarily lowered. In this way susceptibility may be increased, and sickness may more readily follow. To do all that is possible to prevent the usual school-opening increase in illness is the object of these rules.

“It is ordered in the rules that desk tops and banisters be washed with soap and water and afterward be treated with a disinfectant. This is required because disease germs may be planted upon exposed desk tops and banisters by infected persons, and, being transferred by the children’s hands

to their mouths, disease results. The washing and disinfecting will do much to prevent infection from this source.

"Open water buckets and large tin cups are condemned because the dipping of water with cups which are used by many introduce spittle into the supply; and, besides, open buckets catch dust and dirt. Diphtheria, diarrhœa, sore mouth and other complaints have been transmitted in this way. This source of disease may be avoided to a considerable degree by supplying a covered tank with a large free-flowing faucet and a small cup. The opening of a large faucet will furnish a strong stream, which will suddenly fill the cup and wash the saliva from the edge. Ample drainage must be provided for carrying away the waste water.

"Slates are condemned because of their uncleanness. Writing and figures being obliterated as they frequently are with spittle, and as the damp slates readily collect dust, the danger of the transmission of disease in this way is very great. Small children generally place pencils and pens in their mouths, and if these articles are promiscuously distributed without being sterilized, as the rules direct, infection may result. The collecting of pencils seems necessary to always insure one to each pupil.

"Spitting is prohibited because it is a possible source of disease, is filthy and is unnecessary.

"It may seem shocking and unnecessary to many to exclude consumptives from the schools, but when we stop to think that tuberculosis causes one in every seven deaths, killing more people annually than cholera, smallpox, diphtheria, scarlet fever and yellow fever combined, then it is time to lay aside that sentiment and pity which would perpetuate disease and death, and take on those qualities in that higher form which makes them forces for more abundant and better life.

"These rules may seem trifling and unnecessary to those who have not given consideration to modern sanitation, but the teacher more than any other public officer may secure the physical well-being of the pupils as well as their intellectual advancement.

"It is hoped that all the school authorities of the State will promptly enforce these rules."

Special Rules.

RULE 1. All teachers of public, private and parochial schools, all county, city and town health officers and all school authorities shall refuse admittance to the schools under their jurisdiction of any person from any household where contagious disease exists, or any person affected with any evident or apparent communicable disease, or any person who may recently have been affected with diphtheria, membranous croup, scarlet fever, whooping cough, contagious skin disease, measles or other communicable disease, until first presenting a certificate signed by a reputable physician stating that danger of communicating such disease is past, and said certificate is approved and indorsed by the Health Officer in whose jurisdiction the person may reside.

RULE 2. School Commissioners, School Trustees in cities and towns, and Township Trustees, and all authorities governing private or parochial

schools, shall have the school houses under their control put in sanitary condition before school is opened and kept so throughout the year. Floors shall be scrubbed, windows cleaned, desks and all woodwork washed with soap and water and treated with a disinfectant. Windows shall be in repair, so that ventilation may be made perfect. Heating apparatus shall be efficient and in good order, and dirty walls and banisters made clean. Banisters and tops of desks shall be washed with soap and water and treated with a disinfectant once each week.*

RULE 3. School Commissioners, School Trustees in cities and towns, and Township Trustees, shall provide small drinking cups not to hold over a gill. Buckets or pails to dip from are condemned, and reservoirs or tanks of ample size having large, easy acting, free flowing faucets shall be provided. When water is drawn direct from public water pipes or pumps, reservoirs or tanks are, of course, not required. Ample drainage facilities for waste water shall be provided and the pupils directed to allow the cups to flow over when the water is drawn. Drinking cups shall be cleaned and sterilized daily.

RULE 4. Slates are condemned. Paper tablets or pads shall be used instead. Riveted metal boxes of tin or galvanized iron with hinged covers and of proper size, or other approved apparatus to subserve the same purpose, shall be provided for each school room. These are to receive pens or pencils, which must be collected from the children each day, and shall not be again distributed until box or apparatus with the pencils and pens have been sterilized by heating in an oven at or above boiling heat for one-half hour. School Commissioners and School Trustees in cities and towns, and Township Trustees, are directed to enforce this rule.

RULE 5. Heating and ventilating shall be looked after with great care. Every school room shall be provided with a thermometer and a temperature not exceeding 75° Fahrenheit, nor less than 65° be maintained during school hours. School Commissioners and School Trustees in cities and towns, and Township Trustees, are directed to enforce this rule.

RULE 6. Janitors when sweeping shall use damp sawdust or slightly sprinkle, in order to prevent dust. Dusting shall be done with damp cloths. School Commissioners and School Trustees in cities and towns, and Township Trustees, are directed to enforce this rule.

RULE 7. The water supply shall be pure and wholesome, and closet or privy facilities shall be unobjectionable. School Commissioners and School Trustees in cities and towns, and Township Trustees, are directed to enforce this rule.

*The disinfectant for treating desk tops, banisters, etc., and for use in urinals and closets may be cheaply made by the following formula and kept on hand in any quantity desired. To make ten gallons: Chlorinated lime, 40 ounces; soft water, ten gallons. Thoroughly stir together and let stand until clear. The undissolved lime will fall to the bottom and the clear supernatant liquid may be used on the desks, banisters, base boards, etc. The fresh milky mixture, as well as the creamy sediment, may be used in urinals, closets and sinks. This disinfectant is not poisonous or dangerous. Chloride of lime of the best quality may be purchased in quantity for 5 cents per pound. The cost of the disinfectant is, therefore, less than 2 cents per gallon. The use of all patent or secret disinfectants is discouraged by the State Board of Health.

RULE 8. Spitting on the floor of any school building is absolutely forbidden. Teachers and all school authorities are directed to enforce this rule.

RULE 9. School Commissioners and School Trustees in cities and towns, and Township Trustees, shall not employ teachers who are afflicted with pulmonary tuberculosis or any constitutional contagious disease ; neither shall they permit pupils so affected to attend school ; nor shall they permit filthy or unclean pupils to attend the schools under their control.

CHAPTER IV.

GENERAL DEFINITIONS.

PHYSIOLOGY.

Physiology is that science which seeks to discover and interpret those phenomena of plants and animals which we are wont to designate as vital. Man himself belongs to the animal world, and his physiology is to be the subject of this book. But as most of our knowledge of human physiology is derived from experiments on the lower animals, it would be nearer the exact state of things to call this treatise "Studies in Advanced Animal Physiology." But the processes and phenomena of life are universal, and the division into even plant and animal physiology is arbitrary rather than natural. There is but one physiology, because there is but one life, although it may be illustrated in varying aspects in different groups of beings. The plant physiologist as well as the animal physiologist is addressing himself to the solution of the same problem: What is life, and what are its phenomena?

Physiology did not become a science in the real sense of the word until it was discovered that physiological processes were based upon the general laws of nature, and that vital phenomena were never in conflict with inorganic laws. It was not until even recent years, almost in our own decade, that the old notion of a vital energy was finally abandoned. Formerly a phenomenon of life was considered sufficiently explained when it was said that it was the product of a mysterious vital energy, whose workings need not at all be in conformity with the established laws of nature, and which, consequently, could not form a proper subject for scientific inquiry. But the idea of this vital energy is gone forever, and the fundamental maxim of to-

day is that all physiological phenomena (excepting those of consciousness, possibly) may be explained in terms of chemistry and physics. Thus, what uses organs and tissues have, becomes a physical and chemical question in essence rather than a biological one.

ANATOMY.

Before, however, vital phenomena can be studied, it is necessary that we should know the structure of the body exhibiting these phenomena; and so physiology must always be logically preceded by the study of anatomy. As these phenomena usually exhibit themselves in the ultimate biological structure of tissues and organs, anatomy must be extended with the aid of a microscope to the minute structure of every part. The study of this minute structure is designated as *histology*.

COMPARATIVE ANATOMY.

After the structure of the body in question is known, and the function of the various parts established, and possibly even some notion gained as to the care that ought to be exercised in properly preserving it, that is, its *hygiene* understood, our knowledge is still very inadequate. We must compare the form in question with other animal forms, for the most helpful knowledge of anything is frequently that which deals with the relations of that thing to others. Thus, the study of *comparative anatomy* helps to materially clarify the individual anatomy in question.

EMBRYOLOGY.

But even this information is inadequate. Even when we have made extended comparisons with the related forms much is still left unsolved until we know how this individual structure came to be. The science which seeks the sequence of changes which finally leads to the adult form from its primitive beginning in the egg, is the science of *embryology*.

CLASSIFICATION.

When all of these data concerning any living thing are known we have the information at hand to properly classify it in the grand system of nature, and to determine in what group or family it finds its natural place.

A mere glance at the human body reveals a multiplicity of structures, all, however, co-ordinated to one general purpose. Thus, we have the system of the supporting tissues, which preserve the form and sustain the weight of the body; a complicated system of muscles used in performing our movements; a generally distributed nervous system to exercise a controlling influence, and so on through the many instances which might be here adduced. For arbitrary rather than natural reasons the discussion of human physiology is here divided into the following chapters, each of which seeks to treat in detail of some particular system of the body.

CHAPTER V.

THE BLOOD.

GENERAL POINTS.

When an incision is made into a living body there at once streams out a reddish-looking liquid familiar to every one as blood. If this substance, which seems at first sight nothing but a liquid, is examined under a lens, it is found that the liquid itself is not red, but that its color is due to little particles which are colored red, suspended in it. These little particles are the red corpuscles of the blood, whose coloring is due to an iron compound called hæmoglobin. So accustomed have we become to the association of redness with blood that one feels tempted at first view to deny the existence of blood to those forms whose circulating liquid is not colored red. But the blood of most of the invertebrates is colorless and devoid of this pigment.

The necessity for blood is too evident to need comment. Tissues in various parts of the body must have nourishment brought to them and must have their wastes removed, and these results can be obtained only by having a circulating medium which shall answer to this purpose. Some of the few-celled animals so small that the juices may reach all parts of their bodies by the mere process of osmosis, possess no real blood at all. Most of the lower forms are, however, provided with a circulating fluid quite similar to the blood of the vertebrates, except that it contains no red corpuscles. The colorless blood of the clam and oyster are matters of common observation. In some of these invertebrates the liquid itself is colored red with hæmoglobin, as for instance, in the earth worm, whose reddish blood vessels are easily seen through the transparent skin, while in certain exceptional forms actual colored

elements containing hæmoglobin, no doubt identical with blood corpuscles, do really occur. It is a matter of interest that coloring matters other than hæmoglobin occur. Thus in the cuttlefish, some snails, and the lobster, a bluish compound containing traces of copper, called hæmocyanin, colors the blood.

The white corpuscles are distributed throughout the blood of the invertebrate world. When we come to the vertebrated or back-boned animals, there are in addition to these white corpuscles, the red ones. The lowest vertebrate animal (amphioxus), however, possesses no red corpuscles.

AMOUNT.

The amount of blood in the human body has been estimated by a number of observers to be about one-thirteenth of the weight of the body, thus making for the average person from twelve to fifteen pounds of blood, and calculating a pound of blood to measure about a pint, would give us in the neighborhood of one and one-half gallons of this fluid. This amount of blood is at any one time distributed as follows: One-fourth of it is in the heart and the neighboring large blood vessels, one-fourth of it is found in the liver, one-fourth in the capillaries of the voluntary muscles, the remaining one-fourth being distributed over the rest of the body. If fresh blood drawn from the veins or arteries of an animal be allowed to run into a vessel and there prevented from clotting, in a way to be noted later, the suspended particles or corpuscles being a little heavier than the liquid, sink to the bottom and occupy about fifty per cent. of the volume in their wet condition. Examination of these solid particles of the blood reveals two kinds of corpuscles—one the red corpuscle already mentioned, the other the colorless corpuscle, sometimes called lymph corpuscle or leucocyte. The existence of a third corpuscle, that of the plaques or blood tablets, as a distinct structure, is questioned by some physiologists, and a further discussion of this element of the blood is

Fig. 7.—HUMAN BLOOD. MAGNIFIED ABOUT 1000 DIAMETERS. (After Schafer.)

r, r, single red corpuscles seen lying flat; *r', r'*, red corpuscles on their edge and viewed in profile; *r''*, red corpuscles arranged in rouleaux; *c, c*, crenate red corpuscles; *p*, a finely granular pale corpuscle; *g*, a coarsely granular pale corpuscle. Both have two or three distinct vacuoles, and were undergoing changes of shape at the moment of observation; in *g*, a nucleus also is visible.

included in the explanation of the phenomena of coagulation.

THE RED CORPUSCLES OF THE BLOOD.

1.—*Their Size and Form.* The red corpuscles of human blood are biconcave, circular disks having a diameter of $\frac{1}{3200}$ inch. They have no definite membrane and are without a nucleus. In fresh blood these corpuscles show a tendency to run together in rows called rouleaux, the reason for which is not definitely known. The peculiar reflection of the light through the concave center gives to them when viewed with a microscope the appearance of having a nucleus. It is, however, a mere optical illusion. The size of these corpuscles as a rule increases as we go down the animal scale. The largest corpuscles are found in the salamander-like proteus, in which they can be actually individually seen by the unaided eye. In Figure 8 there are indicated drawn to the same scale, the relative sizes and forms of red corpuscles of several different ani-

Fig. 8.—RED BLOOD CORPUSCLES. (After Frey.)

1, human; 2, camel; 3, pigeon; 4, proteus; 5, salamander; 6, frog; 7, snake; 8, lampry. (*a*, surface view; *b*, side view.) (Drawn on same scale.)

mals. With the exception of the camel, whose corpuscles are slightly oval, all the corpuscles of the mammals are round. They are further easily distinguished from those of the lower animals, as in the latter the red corpuscles possess a distinct nucleus. It is interesting that in the embryonic state of the human being nucleated corpuscles occur.

2.—*Color*. When seen singly the corpuscles do not appear red but have a yellowish tint, sometimes shading over into a greenish. This is due, of course, to the dilution of the coloring matter when a single corpuscle is looked at. But the color of ordinary blood is not alone due to the actual color of the hæmoglobin, but also to the reflection of the light from the innumerable little concave mirror-like surfaces of these corpuscles. This explains why blood becomes “laky” in color when the coloring matter is extracted from the corpuscles and dissolved in the liquid. Such laky blood becomes transparent and dark in color. If, on the other hand, certain mineral salts be added to the blood which cause the corpuscle to shrink, the blood

becomes much brighter in color, because owing to the shrinkage of these corpuscles, the light which is reflected from them is correspondingly concentrated.

3.—*Number.* Careful and repeated counts of the number of red corpuscles contained in human blood have been made showing that in a cubic millimeter of blood (small drop) there are in males about five millions, and in females about four and one-half millions. This number varies a little; it is decreased after a hearty meal, after severe hemorrhages, after prolonged fasting, or in such sickness as leukæmia, in which the decrease in number explains the general paleness of complexion. The number to the cubic millimeter varies, however, greatly in different animals. In the form proteus with its huge corpuscles, there are thirty-six thousand; in the frog four hundred thousand; in birds three million six hundred thousand, while in the llama, of South America, it reaches the enormous number of fourteen millions. Compared with the white corpuscles, in human blood there are from four to five hundred red to one white.

4.—*Surface.* In spite of their small size such large numbers give a combined surface which is surprisingly large. Taking the amount of blood in the average body as about six pints, the total surface of all the contained corpuscles would not be far from four thousand square yards. This would be a surface that would require more than eighty steps to walk across it at its shortest distance. It is a surface over twenty-five hundred times greater than the entire surface of the body. As about one hundred and seventy-six cubic centimetres of blood pass into the lungs in each second of time, it means that a corpuscle surface of not much less than one hundred square yards is exposed to the action of the oxygen in this short space of time. Does this not help one to understand the rapidity with which the oxygen is taken up and distributed as well as the amount carried?

5.—*Composition.* The essential element of the red blood corpuscle is the red hæmoglobin imbedded, so to speak, in

the frame work or body of the corpuscle, which latter is called the stroma. As hæmoglobin is soluble in many liquids it can easily be dissolved out of the corpuscle and the colorless body, or stroma left. Hæmoglobin possesses in a remarkable way the ability to unite with oxygen when that gas is plentiful, and to give it up again when the gas is not plentiful. It is this property which gives to it its important function in the body. A large amount of oxygen is required in the body to keep up the relatively high and constant temperature, and to make possible the large expenditures of energy which are necessary to maintain life. The mere liquid plasma of the blood would be perfectly unable to carry this oxygen in sufficient amounts. While this plasma, like water, which is its main constituent, can dissolve a little oxygen—we know that fishes derive their oxygen out of the water in which it is dissolved—our own experience shows us how limited this supply is, and how constantly water must be renewed in aquaria to make possible the existence of life in it. It is estimated that the hæmoglobin carries about nine-tenths of all the oxygen. It is not necessary to call attention to the result that would follow doing away with this hæmoglobin and so reducing the oxygen supply ninety per cent.

The Oxygen-carrying Property of Hæmoglobin.

The at first puzzling question, why the hæmoglobin should unite with the oxygen in the lungs and then give it up in the tissues and not attempt at times to carry the oxygen from the tissues to the lungs, is easily explained on physical and chemical grounds. Hæmoglobin will combine with the oxygen when it is exposed to an atmosphere that has a pressure of at least one-sixth of the normal atmospheric pressure. Exposed to an atmosphere less than one-sixth of the normal pressure it not only refuses to unite with oxygen, but actually disunites with the oxygen which it already has and sets it free. Now we know that the atmosphere is composed of about four-fifths of nitrogen and

one-fifth of oxygen, and as the combined pressure of these two gases is, generally speaking, fifteen pounds to the square inch, it is evident that the oxygen part of that pressure is one-fifth of that, or *three pounds*, while in an atmosphere diminished to one-sixth of fifteen pounds, or two and one-half pounds, the oxygen part of this would be one-sixth of three pounds, or one-half pound.

To state it again, hæmoglobin will unite with oxygen when it is exposed to an oxygen pressure of one-half pound or more, and will not only refuse to unite, but actually dis-unite when it is exposed to an oxygen pressure less than one-half pound. As the oxygen pressure in the lung is three pounds, it explains the union with that gas there, while the fact that it gives up its oxygen in the tissues is accounted for by the simple physical reason that the oxygen pressure in the tissues is less than one-half pound, as the oxygen there is being continually used up by the hungry tissues. Why this hæmoglobin should be "boxed up" in corpuscles and not simply dissolved in the plasma of the blood, is evident. It could carry as much oxygen in one case as in the other; but as much of the plasma soaks through the capillaries, becomes lymph, bathes the tissues, and only after a considerable time is finally poured back into the blood stream, it means that any hæmoglobin dissolved in this would have been able to carry but one load, instead of a hundred, possibly, by being whirled along with the blood stream.

When combined with oxygen (then called oxyhæmoglobin) it is of a bright red color, the color of arterial blood. Hæmoglobin is an albuminous compound characterized by a relatively large amount of iron, although in actual quantity the iron contained is less than one-half of one per cent. This iron, however, plays a very important role in the oxygen-carrying process. The rapidity with which ordinary iron unites with oxygen, or as we say, "rusts," may account for its presence here.

Blood Crystals.

As before stated, hæmoglobin can be dissolved out of a corpuscle by adding to the blood an excess of water, chloroform, or other solvent. If to such a solution, made icy cold, some alcohol be added, the hæmoglobin will separate, and fall to the bottom as well-defined red crystals called blood or hæmoglobin crystals. It is exceedingly

Fig. 9.—HÆMOGLOBIN CRYSTALS.

1, a typical crystal.

Fig. 10.—HÆMIN CRYSTALS.

difficult to preserve these crystals, as they disintegrate easily.

Under ordinary circumstances hæmoglobin disintegrates into an albumen called globulin, and into a dirty brown substance called hæmatin. Hence the dirty brown red appearance of old stains and the discoloration of the skin which follows a severe bruise and is familiar to every boy as a "black eye." The discoloration of the skin is due to the blood which has stagnated in the bruised tissues, the hæmoglobin of which has disintegrated into a substance almost identical with hæmatin called hæmatoidin.

Sometimes it becomes desirable to establish the identity of stains believed to be blood stains. It is not at all unusual in legal proceedings incident to murder trials, to attempt to prove that certain spots or stains are really blood stains. Such a proof is easily made. If from the old blood stain some of this dark hæmatin be removed to a

glass slip, a crystal of common salt added, and a drop of glacial acetic acid poured over it, the hæmatin will unite with some hydro-chloric acid liberated, and form characteristic crystals called hæmin crystals.

The Spectrum of Hæmoglobin.

Another characteristic property of hæmoglobin is its absorption lines when viewed with a spectroscope. When ordinary white light is viewed with a spectroscope it is broken up into those characteristic colors with which we are familiar as the spectrum. If, now, such a beam of ordinary light be passed through a solution of oxyhæmoglobin before reaching the spectroscope, the spectrum is not complete; but there appear two very dark black lines in that part of the spectrum where the red shades over into the yellow and that into the green. If now the oxygen be taken out of the oxyhæmoglobin and a ray of light passed through this venous hæmoglobin be examined, there appears in the spectrum one dark band, in position almost exactly between the two stripes of the oxyhæmoglobin. This single absorption band for the hæmoglobin, and the two bands for the oxyhæmoglobin are so characteristic that

Fig. 11.—SPECTRUM OF HÆMOGLOBIN AND ITS COMPOUNDS. (C, D, E, etc., Fraunhofer lines.)

the presence of very small amounts of blood in any solution can be established beyond a doubt.

Hæmoglobin shows a strong affinity for carbon monoxide, the poisonous substance which forms a large part of ordinary illuminating gas. This affinity is in fact so strong that when the hæmoglobin has once united with the carbon monoxide it is almost impossible to displace it. This fact renders gas poisoning extremely dangerous, for even when such a patient is brought into the fresh air, he is unable to get oxygen, because the hæmoglobin will not let go of its carbon monoxide, and so he is liable to suffocate even in an oxygen atmosphere. Hæmoglobin so united with carbon monoxide has a bright arterial appearance, and persons who have died of gas suffocation maintain the bright arterial color even long after death. Such a corpse retains a redness of skin which makes it at first sight seem almost impossible that the individual should be dead. As accidents of gas poisoning are not at all infrequent in cities, it is worth while to know how to establish such a cause of death.

In addition to the hæmoglobin, which amounts in a dried corpuscle to over ninety per cent., there is an albumen called globulin, further traces of fat, and of two organic substances, cholesterin and lecithin (to be studied further in later chapters), and finally salts of potassium, phosphates, and traces of ordinary common salt. In the live condition of the corpuscle a large quantity of water enters into its constitution.

6.—*Consistency.* In consistency the red corpuscle seems to be made up of a homogeneous, jelly-like substance which possesses remarkable powers of elasticity. In examining the blood streaming through the blood vessels one may find here and there a corpuscle caught where an artery divides, very much stretched out of its natural shape, yet springing back to its original form as soon as the stress is over. This is no doubt a valuable property in enabling the

corpuscles to elbow their way through the delicate capillary channels.

7.—*The Origin of the Red Corpuscles.* One of the most difficult chapters in physiology is that dealing with the origin of the red corpuscles, and a number of conflicting theories are even now seeking support. To trace the origin of the red corpuscles it is necessary to study the blood of an animal before its birth. Such examination of human embryos shows that in early uterine life the red corpuscles are nucleated and possess the power of amœboid movement. They are, in fact, very similar to the white corpuscles of the blood except that they are colored with hæmoglobin. These corpuscles arise in this way:

Some of the connective tissue cells become somewhat elongated and have their nuclei divide up into many

Fig. 12.—EMBRYONIC DEVELOPMENT OF BLOOD CORPUSCLES IN CONNECTIVE TISSUE CELLS, AND THE TRANSFORMATION OF THE LATTER INTO BLOOD CAPILLARIES. (After Schäfer.)

a, an elongated cell with fluid protoplasm and containing corpuscles which are still round; *b*, a more hollowed cell in which the corpuscles have become disc-shaped; *c*, the manner of union of such a tissue cell (*c h*) containing here only one corpuscle with an already formed capillary. (*a* and *c* from a new-born rat, *b* from a fœtal sheep.)

smaller nuclei. These nuclei soon seem to round themselves, become tinted red with hæmoglobin, and are in fact the nucleated red corpuscles of the embryo. The connective

tissue cells in which by a nuclear division they were formed, elongate very rapidly and soon touch similar elongations of neighboring tissue cells. Where they touch, the partition dividing them melts away and the cavities of the cells are converted into a system of capillaries. This system of capillaries is soon connected with larger blood vessels and so these nuclei find themselves in the general circulation at once. The protoplasm of the tissue cell becomes liquified and helps to form the plasma of the blood. This intra-cellular mode of development of red blood corpuscles does not continue after birth, unless it be in animals such as the rat, which are born in a very immature condition. For this reason we must in the adult body seek for their origin elsewhere.

It is now fairly well established that in adult life they arise in the red marrow of the bones. In this red marrow there may be observed corpuscles which seem identical with the nucleated red corpuscles of the embryo. In fact, it seems probable that the nucleated embryonic corpuscles migrating into the red marrow of the bones have been the lineal ancestors of the nucleated red corpuscles in the adult marrow. These corpuscles seem to divide like ordinary

Fig. 13.—HÆMATOBLASTS IN PROCESS OF DIVISION. From the red marrow of the Guinea-pig. (After Schafer.)

corpuscles, possess the power of amœboid movement, and differ from the ordinary white corpuscles apparently in little more than the possession of the hæmoglobin. These nucleated red corpuscles form the ordinary non-nucleated corpuscles of the blood by having the nucleus gradually atrophy and disappear. In fact, according to some observers the nucleus is said to be extruded from the corpuscle and then dissolved, while the non-nucleated body is carried away by the blood stream as a newly created blood corpuscle. These marrow corpuscles have been called ery-

throblasts or more frequently hæmatoblasts. The view is held by many observers that these hæmatoblasts are not the lineal descendants of the nucleated red corpuscles of the embryo, but are being regularly derived from the ordinary white corpuscles of the blood found in the marrow.

8.—*Length of Life of Red Corpuscles.* That red corpuscles are being produced daily in great numbers is evident from the fact that so many are destroyed in the spleen and liver. The coloring matter of the bile is derived from disintegrated red corpuscles, and the number of corpuscles required to color to such an extent the large amount of bile daily eliminated exceeds calculation. It is, of course, not possible to tell how long a red corpuscle will retain its vitality and properly perform the functions ascribed to it, but there are reasons to believe that the ordinary length of life of such a corpuscle varies from three, to possibly not more than eight or ten weeks. To replace the entire number of corpuscles in the body every two months means a daily manufacture of them by the billions. In fact, it seems a little like a fairy story to be told that for every beat of the pulse nearly twenty millions of these organisms die. Such a wholesale manufacture of them is to be explained by the rapidity with which these hæmatoblasts are supposed to divide. The older view that red corpuscles were directly derived from the white ones, or from the blood tablets, has been abandoned as not at all in accordance with observed facts. The red or blood-forming marrow is found in the extremities of most of the bones of the trunk, and in the bones of the skull. It is interesting that when the blood-formation process is very active the yellow marrow itself may be changed into red through all the bones.

9.—*The Destruction of the Red Corpuscles.* The fact that corpuscles are short lived brings up naturally the question as to the manner of their destruction and elimination. As the pigments of the bile are derived from broken down corpuscles there is no doubt that many of them are

disintegrated in the liver. Just in what manner we do not know. In the spleen, too, there occur so-called blood-corpuscle-containing cells, that is, large white corpuscles which seem to have eaten up decrepid corpuscles and to be in the process of digesting them. Just how these cannibal cells are able to single out worn-out corpuscles and leave normal ones untouched is probably accounted for by the fact that old corpuscles are sticky, and so remain attached, while normal ones are carried on with the blood stream.

THE WHITE OR COLORLESS CORPUSCLES.

Much less numerous than the red are the white corpuscles of the blood. These corpuscles may be taken as types of a living cell, possessing in some degree all the properties that characterize ordinary one-celled animals. As given before, the number of the white as compared with that of the red is about one to three or four hundred. They vary much in size, many of them are even smaller than the red corpuscles, others differ but little from them, while the larger ones measure from one and one-third times to twice the size of the red. They possess no cell wall, but seem composed throughout of a granular kind of proto-

Fig. 14.—FORMS OF A WHITE BLOOD CORPUSCLE SKETCHED AT INTERVALS DURING ITS AMOEBOID MOVEMENTS.

a, Beginning of movement; *b*, formation of pseudopodia; *c*, the nucleus itself changes its form; *d*, the corpuscle at last dead.

plasm in which is imbedded the large, clearly discernible nucleus. Their most remarkable property is that of being able to throw out processes called pseudopodia and to wander from place to place like the ordinary fresh water amœba, hence these motions are called amœboid. By virtue of this amœboid movement the white corpuscles are able to wander through the spaces between the tissues, and even to bore their way through the delicate walls of the capillaries. When such a phenomenon is viewed under a microscope it is seen how a corpuscle will attach itself to the side of the capillary, probably by virtue of its natural stickiness. Soon there is seen projecting on the outside of the capillary a tiny little process which gradually becomes larger at the expense of the corpuscle until finally the full corpuscle has thus wedged its way through. This phenomenon of wandering out of capillaries is especially marked in the early stages of inflammation when the holes so made through the capillaries frequently become so large and so numerous as to permit the red corpuscles to be mechanically forced through, and thus for the blood itself to seep into the tissues, hence no doubt the redness and the swelling of the inflammation. By virtue of this movement they are further able to pick up foreign particles by flowing around the particle until it is included in the cell, a method exactly similar to that of the amœba when it secures its food. Foreign particles are thus literally eaten up by these cells.

As mentioned in a previous chapter, it is highly probable that bacteria which find their way into the blood are thus mechanically picked up and so rendered harmless. Particles injected into the blood of transparent animals, such as the water flea, being picked up by the colorless corpuscles of the blood, may be watched under the microscope. They probably serve in the disintegration of old tissues, for it is possible to find in the blood of some amphibians when they are losing their tails, such as the change from the tadpole to the frog, some of these cells

actually containing bits of muscle and nerve of the disintegrated organ. Being thus able to wander up and down the avenues of the body, in, between, and through the tissues, they have been called wandering cells. For this reason these corpuscles are not at all confined to the blood, but occur with a similar frequency in lymph, in the marrow of bones, and probably the so-called connective tissue corpuscles are but slightly differentiated white corpuscles. Their migration in the formation of pus has been mentioned in a preceding chapter.

It seems probable that these corpuscles are instrumental in absorbing the fat from the intestines by mechanically carrying it from the villi into the lacteals, while the fat circulating in the body which is not needed by the tissues is carried by such corpuscles and stored away in different parts forming adipose tissue. Such fat-eating cells, sometimes called plasma cells, may become so distended with fat that the cell body is reduced to a slight envelope surrounding the huge fat globule. White corpuscles possess the power to multiply by the process of ordinary cell division. This may occur any place in the body, *e. g.* in the blood, but more regularly occurs in what are known as lymphatic glands.

Lymphatic glands are not glands in any true sense of that term, but are large aggregations of white corpuscles housed in a capsule of connective tissue. The fact that through such capsules lymphatic vessels flow, has given them the name of lymphatic glands. In these glands the cells grow and divide, and by the lymph stream circulating through it the additions are carried out into the body. Such lymphatic glands are familiar to us as the tonsils, the thymus gland, the patches of Peyer, and numerous little lymphatic nodules distributed all over the body. In the spleen, too, these corpuscles seem to be formed in an analagous way.

The fate of these corpuscles is difficult to determine in all cases. There is reason to believe that in addition to the

cells which are lost in the formation of pus, worn-out corpuscles are sent to the spleen and the liver to be disintegrated. That these white corpuscles may take part in the

Fig. 15.—LYMPHATIC GLAND, DIAGRAMMATIC SECTION. (After Sharpey.)

a, l, lymphatic running into gland; *e, l*, same issuing; *C*, connective tissue capsule; *M, tr*, connective tissue ground work; *l, s*, lymph space; corpuscles indicated in part of gland only.

formation of new tissues and so, becoming differentiated, become muscle or connective tissues, or whatever tissue needed, is stated by many observers but denied by others, and future investigation must settle the dispute. The relation of these corpuscles to the coagulation of blood is mentioned in the discussion of that process.

THE BLOOD PLATES.

Recently attention has been called to a third corpuscle of the blood, the blood plates, blood tablets, or blood plaques. These are corpuscles much smaller than the red corpuscles, are pale or colorless, and in shape vary from the round to the decidedly oval form. Their number has been given by

observers as varying from eighteen thousand to twenty-five thousand in a cubic millimeter of blood. They break down with remarkable rapidity as soon as blood is shed, and this

Fig. 16.—BLOOD CORPUSCLES AND PLATELETS IN A SMALL VEIN OF THE RAT'S MESENTERY. (After Osler.)

probably may account for the fact that they were only recently discovered. Just where these come from is still a matter of question. By some they are believed to be merely parts of disintegrated white corpuscles, but as they have been observed in the circulating, unharmed blood, this view is probably not correct. Possibly they are nothing more than very small white blood corpuscles. A very important role has been assigned to these little plates, because it is believed by a number of physiologists of rank that in the disintegration of these plates the fibrin ferment is formed, which starts the coagulation of the blood. The fact that they disintegrate so rapidly when the blood is put under an abnormal condition may be for the purpose of setting going at once this process of coagulation.

Historical.—The colorless corpuscles were discovered by Hewson, and their amoeboid motions, in the case of human corpuscles, by Davaine in 1850. The blood tablets were first described by Bizzozero.

THE BLOOD PLASMA.

The liquid part of the blood is called the blood plasma. When the corpuscles are removed from it it has a clear, slightly yellowish color, a rather insipid sweetish taste, is a little alkaline in its reaction, and of a specific gravity a little greater than water. Its most striking property is its power to form in a rather short time a so-called clot, and a thorough understanding of the composition of this liquid must be preceded by a discussion of the process of coagulation.

THE COAGULATION OF THE BLOOD.

It is a matter of common observation that when the blood is allowed to stream from a severed vessel into a jar it forms in a very short time a solid, trembling jelly. This happens in the blood of a pigeon almost instantaneously; in the blood of a horse, coagulation is slower, while in man it is medium. Soon the top of the jelly or clot becomes cupped, and a transparent or slightly colored liquid appears over it. This cupping is due to the contraction of the clot, which, continuing, soon pulls the clot loose from the walls of the vessel, and by its continued contraction forces out larger and larger quantities of the liquid just referred to, which is called serum. If the blood had been prevented from clotting so rapidly, which might have been done by subjecting it to a cold temperature, the corpuscles would have settled to the bottom, leaving a clear liquid on top. As the white corpuscles are not quite as heavy as the red, they are the last to settle, and there is formed a whitish layer over the top called the "buffy coat."

As soon as the temperature is raised the blood begins to clot. If blood, however, as it is streaming into the jar be stirred with a stick, or as we say, "whipped," it does not clot regularly at all; but there may be seen collected on the stick a bundle of threads whose removal from the clot has prevented the blood from solidifying. If these threads be removed from the stick and carefully washed to free them from entangled corpuscles, they are seen to consist of a mass of stringy matter which has been called fibrin. Evidently the clotting of the blood is due to the formation of these threads all through the clot, in the meshes of which threads the corpuscles are mechanically included. The later contraction of these threads squeezes out the contained serum. The difference, therefore, between blood plasma and blood serum is the absence of the fibrin from the latter. Just from what this fibrin comes, and what are the causes that have led to its sudden formation are questions for further study.

Without going into the many controversies of this problem, the most generally accepted theory is here given in explanation of coagulation; but it must be remembered that many points are not yet clear, and that the observations of the future may materially change our present notion. According to the observations of Alexander Schmidt, later modified by Hammarsten, there are in the blood three main albumens. These are fibrinogen, fibrinoplastin, sometimes called paraglobulin, and serum albumen. The serum albumen takes no part in the coagulation, and its purpose in the blood is to afford a nutritive substance for the tissues. If the blood plasma had no other function, this one albumen would no doubt suffice as a food for all cells of the body; but as serum albumen clots only when subjected to the action of heat or strong chemical reagents the coagulation of the blood would be impossible, and the danger from hemorrhages would be always imminent. To prevent this loss of blood other albumens are added. Of these, fibrinogen possesses the property of being easily changed into fibrin under certain definite conditions. To follow these successive stages in detail let us imagine the finger suddenly cut. As soon as the incision is made into the flesh and the vessels traversing it, the blood finds itself in an abnormal condition and the blood tablets at once begin to disintegrate, no doubt because they are not able to live under the changed environment. In their disintegration they form a substance which is called fibrin ferment. This fibrin fer-

Fig. 17.—NETWORK OF FIBRIN THREADS RADIATING FROM SMALL CLUMPS OF BLOOD-PLATELETS. (After Schäfer.)

ment at once reacts upon the fibrinogen, causing that to change into fibrin, and thus a clot arises. A somewhat analogous case might be cited in the curdling of milk by

means of the ferment known to every cheese-maker as "rennet." If a little of this rennet be added to even large quantities of milk, in a very short time, by the action of this ferment, the milk curds. It has not been possible to get fibrin ferment pure, but neither have we been able as yet to get rennet in a similar form. This fibrin ferment is probably not produced in a purposive way by the tablets, but results as a mere element of disintegration when they die. Thus the strings of fibrin in the clotted blood existed in the normal blood in the form of the liquid, fibrinogen. This liquid did not change into fibrin, because no fibrin ferment is present in normal blood, for the reason that the blood plates do not disintegrate under such normal conditions. It has been noted, though, that if a solution containing such a ferment be injected in considerable quantities into the veins of an animal, internal coagulation at once results. The presence of fibrinoplastin seems to facilitate this process, although it takes no direct part in it, for the blood serum has as much fibrinoplastin as it had before the clotting took place. Just how the substance may facilitate a chemical process without directly taking part in it does not seem clear, but chemistry offers a number of analogies. Fibrinogen will not, however, change into fibrin, even in the presence of the fibrin ferment, unless there be found in solution in it certain salts, especially common salt and the salts of lime. If by adding a little oxalic acid the lime salts are removed from fresh blood it does not coagulate at all. This fact has led some observers to believe that the fibrin was really a compound of the fibrinogen and the calcium, a calcium-fibrinogenate.

Possibly this matter of coagulation may more easily be understood by following the method of making an artificial clot. If a solution of pure fibrin, such as may be secured from a hydrocele fluid, be put in a vessel, it will not coagulate instantaneously at all. If now to this fibrinogen traces of common salt and lime salts be added, and then some fibrin ferment introduced, it will begin to coagulate at once,

and the clot seems in every way a typical normal blood clot. If, however, some fibrinoplastin had also been added, the clot would have formed a little more quickly, but the final product would not have differed from the first in any noticeable way.

The question naturally arises why blood does not coagulate in the body? If a blood vessel be removed from the body and the ends tied, the blood will not clot for hours. In fact, it is possible to cut out a turtle's heart and have the blood remain liquid in it for seven or eight days, and yet such blood when exposed in many other ways begins to clot at once. Some have tried to ascribe to the lining of healthy blood vessels a sort of inhibitory function, but this is a mere explanation of words and not of ideas. The point remains that for some yet unexplained reason the fibrin ferment does not seem to have been produced, possibly because the blood plates and corpuscles have not been disintegrated in a way calculated to produce this ferment. Such abnormal conditions as a bruised blood vessel, exposure to the air, contact with foreign bodies, serve to disintegrate them and so start the process of coagulation.

While in the discussion so far the formation of the fibrin ferment has been attributed to the blood plates, there is little doubt but that the white corpuscles as well, in their disintegration, form this fibrin ferment. This may explain why in certain diseases of the body in which corpuscles disintegrate in large numbers internal clots have been formed, interrupting the circulatory course and so causing death. It is not an infrequent observation too that in persons suffering from blood poisoning, a disease in which large quantities of corpuscles are lost, there is a tendency towards the formation of internal clots, which frequently prove fatal before the full effects of the blood poisoning have had time to arrive. In fact, in fevers generally the amount of fibrin ferment in the blood seems a little more abundant. While in the daily life of a healthy individual many such corpuscles disintegrate, they do not do so in sufficient numbers

to form material amounts of fibrin ferment, and so the blood is prevented from clotting. Though this explanation at first sight seems sufficient, a closer study shows that it does not yet answer all the observed facts in coagulation of blood, and there are many observers who offer modified theories to account for this phenomenon. Thus, we do not know from what source the fibrinogen is derived. Al. Schmidt, the originator of the theory here given, believes that the fibrinogen and the fibrinoplastin both, as well as fibrin ferment, are derived from the disintegration of white corpuscles. This might explain why at the point where clotting begins and where, therefore, large numbers of these corpuscles are dissolved, added amounts of fibrinogen should form and thus facilitate clotting.

But to recapitulate: The best explanation now available is that there is present in normal human blood dissolved in the plasma about two-tenths per cent. of an albumen known as fibrinogen. This fibrinogen in the presence of common salt and lime salts will change into insoluble fibrin threads under the influence of this fibrin ferment, at present believed by all to be derived from the colorless corpuscles of the blood. The property of coagulation is by no means peculiar to fibrinogen. Most albumens possess it more or less fully shown. The liquid casein of milk easily coagulates into cheese under the action of the rennet ferment. The liquid albumen of living muscles soon clots after death, producing the so-called death stiffening, or rigor-mortis. Even ordinary egg albumen can easily be made to coagulate by the action of heat or chemical agents.

The liquid that is left after the blood has clotted is called serum.

THE COMPOSITION OF SERUM.

The serum of ordinary blood contains about ninety per cent. of water. It contains two albumens which have indirectly taken part in the formation of the clot called fibrinoplastin and serum albumen. This serum albumen must not

be confused with the serum itself. Serum is the name applied to the entire liquid after the fibrinogen has been removed in the form of fibrin, while serum albumen is but one of the albumens found in this liquid. Fibrinoplastin, so called by Al. Schmidt, and called paraglobulin by Kühne, is present to the amount of about one per cent. The serum albumen forms four or five per cent. These two albumens are insoluble in pure water, but are soluble in water containing a little common salt, which latter accounts for their being in solution in normal blood. The two differ but very little from each other, but they may be separated if to a solution of serum at a temperature of about ninety-five degrees Fahrenheit, crystals of magnesium sulphate be added to saturation. The fibrinoplastin is by this process precipitated out of the solution.

As stated before, the serum albumen is the main nutritive factor of the blood. It is almost identical with liquid egg albumen, and differs from it only in its reaction with certain chemical agents. It is this albumen which in pathological conditions of the kidneys, such as Bright's disease, is eliminated in the excretion. Both serum albumen and fibrinoplastin may be made to coagulate if blood serum be heated to a temperature of about one hundred and seventy-six degrees Fahrenheit.

The serum further contains traces of fat in the form of fine granules, to the amount of about one-half per cent. After a diet rich in fats the amount may reach one per cent. Traces of grape sugar in amounts varying from one-tenth to three-tenths of a per cent. occur. This amount may also greatly vary with a diet rich in sugars. It further contains in very small amounts a number of organic nitrogenous compounds, such as kreatin, urea, and uric acid, substances with which we shall be further concerned in the discussion of assimilation and nutrition. The mineral salts are represented in an amount reaching not quite one per cent. Of these common salt, or sodium chloride, forms more than half, and sodium carbonate a good portion of the

remainder. It is an interesting fact to note that while the potassium salts are contained so largely in the corpuscles, the sodium salts figure in a similar role in the liquid. A yellow pigment of a nature not understood, and traces of a substance to which the characteristic odor of blood is due, finally complete the list of things which enter into the composition of blood. There are, of course, dissolved in the blood certain gases, but the discussion of these is postponed to the chapter on respiration.

In the discussion of blood, that of lymph is naturally included, lymph being in fact nothing but the plasma of the blood which has by osmotic processes soaked through the walls of the capillaries and so bathed the tissues. To use an arithmetical expression, lymph is blood minus the red corpuscles. White corpuscles are present in lymph owing to the fact that they are able to pass through the capillary walls, and in general are able to wander among the tissues. Occurring so plentifully in lymph, has given to them the name by which they are frequently called, that of lymph corpuscles. It is well to keep in mind that the migration of these corpuscles through the walls of the capillaries, as it is normally done, does not necessarily injure them. Probably they press their way through tiny openings made between the cells which form the capillary wall. In any case the opening made is so small that it is at once closed up.

THE PHENOMENON OF OSMOSIS.

The phenomenon of osmosis referred to so frequently in physiological discussion is the phenomenon of the diffusion of liquids through a membrane in such a way that the compositions of the two liquids tend to become similar. Thus, if a moist animal membrane, such as a stretched bladder, be taken and placed so as to divide a vessel in two compartments, and then water containing sugar be placed in one compartment, and salty water in another, osmotic currents are soon set up through the membrane, by means of which

part of the sugar is carried to the salty side and part of the salt to the sugary side. These currents continue so, secondary causes not preventing, until the proportion of sugar and salt are the same throughout. In an exactly similar way the plasma of the blood containing in solution a number of nutritive substances passes through the wall of the capillary into and between the tissues, where these nutritive substances are being continually taken up by the tissues, and so an equilibrium never established. On the other hand, a number of waste products which are formed in the tissues pass into the blood.

CHAPTER VI.

THE SUPPORTING TISSUES.

The supporting tissues are comprised of those tissues which give support to the delicate organs of the body and their component cells. They are distributed throughout the entire body and give form and shape to the same. Including all the connective tissues and not merely the bony skeleton, these supporting tissues would preserve the actual size, appearance, and contour of the body, even if every vestige of their tissues could be removed. The body with nothing but its system of supporting tissues would remain apparently so unaltered that the absence of all the vital parts might not even be suspected by the observer.

The supporting tissues naturally fall into four divisions: First, the osseous; second, the cartilaginous; third, the connective; and fourth, the humors. All of these tissues are alike, in the fact that they are formed not out of cells, but from the product of cells, somewhat in the way in which a cobweb is formed—not out of spiders, but as the product of their secretion. Not being made up of living cells, therefore, these tissues are in a sense dead matter, although the cells that produce them frequently remain in the tissue, forming a very integral part of its structure. The cells that produce bone are called bone corpuscles, or osteoblasts; the cells that form cartilage are the cartilage cells, or chondrioblasts; those that form the connective tissues and the humors are called connective tissue corpuscles. All of these cells resemble very closely the white corpuscles of the blood, and are probably nothing but slightly differentiated cells set apart for the purpose of secreting and maintaining the supporting frame-work of the body.

Fig. 18.—THE ENTIRE SKELETON.

a, b, skull; *c*, cervical vertebræ; *d*, sternum; *e*, lumbar vertebræ; *f*, ulna; *g*, radius; *h*, carpal bones; *i*, metacarpal bones; *k*, phalanges; *l*, tibia; *m*, fibula; *n*, tarsal bones; *o*, metatarsal bones; *P*, phalanges; *q*, patella; *r*, femur; *S*, os innominatum; *t*, humerus; *u*, clavicle.

Bony Tissue.

Osseous tissue is familiar to every one as the tissue of which bone is composed. The bones of the body in their proper articulations form the skeleton. The skeleton consists of a trunk, two pairs of extremities, their supporting girdles, and the skull.

The trunk is composed of seven cervical vertebræ, twelve dorsal, five lumbar, the sacrum, and the coccyx.

Fig. 19.—SPINAL COLUMN.
(Side view.)

C, cervical; D, dorsal; L, lumbar; S, sacrum; Co, coccyx.

VERTEBRÆ.

The first vertebra called the atlas differs from the rest in that the body of the atlas has grown to the next vertebra, the axis, forming a pivot, the odontoid process on which the head turns. The cervical vertebra has a few characteristics by means of which it may be

Fig. 20.—ATLAS. (Seen from above.)

Dotted lines, position of transverse ligament to hold in place the odontoid process; oblique line, insertion of ligament into a bony tubercle; other lines, articulating surfaces.

Fig. 21.—ATLAS AND AXIS, FRONT VIEW.

Upper line, odontoid process; remaining lines, articulating processes.

Fig. 22.—A TYPICAL CERVICAL VERTEBRA.
Showing intra-vertebral foramen and bifid spinous process.

recognized. Its spinous process is bifid, and the transverse process appears with an opening called the intra-vertebral foramen. Through this the intra-vertebral artery ascends to the brain. This is not really a hole through the transverse process of the cervical vertebra, but is a space left between the transverse process and the stump of a rib which is fused with it, there being in early life indications of the presence of ribs throughout the cervical region. The dorsal vertebræ are at once recognized in having the articulating facets for the ribs, and in having their spinous processes

Fig. 23.—A DORSAL VERTEBRA FROM THE
RIGHT SIDE.

Two upper lines, facets for the articulation of ribs; left line below, inferior articular process; middle line below, vertebral notch (exit of nerves, etc.); right line below, facet for lower rib.

Fig. 24.—LUMBAR VERTEBRA FROM
ABOVE.

Upper line, inferior articulating process; lower line, superior articulating process.

drawn downward. This latter arrangement is better adapted for the attachment of the heavy muscles of the body. The lumbar vertebræ have proportionately a much larger body, and the processes relatively much shorter and thicker. The sacrum consists in reality of five fused vertebræ, the individual ones being still clearly traceable on it. This fusion

Fig. 25.—THE SACRUM, FRONT VIEW.

aids materially in giving strength to that portion of the column where it is connected with the hip bone. The coccyx consists of from two to four or five very much reduced vertebræ and serves as far as we know no special function. The individual vertebræ are separated by pads of elastic cartilage which give them a certain amount of lateral motion, and which also serve as cushions to break the jars. The double curvature of the entire column still further serves to reduce this to a minimum.

RIBS.

Attached to the dorsal vertebræ are twelve pairs of ribs, which extend slightly downward, then upward, and enclose the organs of the chest. With the exception of two on each side, called the floating ribs, they are attached to the sternum, or breast bone, by means of elastic cartilages, which permit a slight movement at these points.

PECTORAL AND PELVIC GIRDLES AND THE EXTREMITIES.

More or less firmly attached to this trunk are the two girdles of the body, the pectoral girdle, supporting the arms, and the pelvic girdle, for the attachment of the limbs. The pectoral girdle consists on each side of two bones, the

Fig. 26.—RIGHT CLAVICLE, FROM ABOVE.

Fig. 27.—ANTERIOR VIEW OF RIGHT SCAPULA.

clavicle and the scapula. The clavicle articulates with the manubrium of the breast bone and with the large acromion process of the scapula. This serves to hold the shoulder back in place. Animals that walk on their four limbs have the clavicle reduced to a mere splint or thread of cartilage, as it would be in their case undesirable to have the shoulders pitched back. This reduction of the clavicle allows the shoulders of these animals to drop under the body, a position much better suited for supporting their weight.

The scapula, or shoulder blade, is not connected with the back bone, but lies imbedded in the muscles of the shoulder. This loose attachment aids materially in giving freedom of motion to the arm. The scapula really consists of two bones, the scapula proper and the coracoid bone, which latter, however, has been reduced to a mere process, which has grown on to the scapula, and which is called the coracoid process. In birds this coracoid process is a very large and distinct bone, and serves to support the wings,

Fig. 28.—THE RIGHT HUMERUS FROM BEFORE.

Fig. 29.—THE BONES OF THE RIGHT HAND SEEN FROM BEFORE.

s, scaphoid; *l*, lunar; *c*, pyramidal; *P*, pisiform; *t*, trapezium; next, the trapezoid; then, the osmagnum; *u*, unciform; *I, V*, metacarpals; *1, 2, 3*, phalanges; *, sesamoid bones.

while the clavicle loses its attachment with the breast bone, and meeting the clavicle on the other side forms the so-called "wish bone." Articulating in the glenoid fossa of the scap-

ula is the bone of the forearm called the humerus. This articulates at the elbow with two bones, the radius and the ulna. The ulna forms the main articulation, forming really the hinge joint of the elbow. The backward process on the ulna, which prevents the backward flexion of the elbow joint, is called the olecranon process. This is really an elbow cap, similar to the knee cap, which, however, in this case has become firmly attached to the ulna.

At the wrist the radius and ulna articulate with a series of eight bones called the carpal bones. Here the radius forms the main articulation, and by rotating around the ulna the hand is pronated and supinated. These carpal bones are followed by five metacarpal bones, to which in turn are connected three phalanges for each finger, the thumb having but two. The radius is on the thumb side of the wrist.

Fig. 30.—RIGHT OS INNOMINATUM.

Attached to the sacrum on each side is the os innominatum, so called because the early anatomists were not able to name it after any object they knew. This bone

really consists of three bones, which have grown together, the large flat upper ilium, which connects with the sacrum, the lower ischium, which supports the weight of the body in a sitting posture, and the forward pubic bone, which by

Fig. 31.—ADULT MALE PELVIS, SEEN FROM BEFORE. (Upper.)
ADULT FEMALE PELVIS, SEEN FROM BEFORE. (Lower.)
(After Allen Thompson.)

articulating with the pubic bone on the other side forms the front wall of the pelvis. The large articulating facet for the head of the femur is called the acetabulum. A large hole formed through the bone, the thyroid foramen, serves for the exit of nerves and blood vessels from the pelvic cavity. Attached to the innominate bone is the femur, the long bone of the thigh. This articulates at the knee with the tibia.

Along the outside of the tibia and serving to brace this articulating surface with the femur lies the smaller fibula.

Fig. 32.—RIGHT TIBIA AND FIBULA, FROM BEFORE.

Fig. 33.—RIGHT RADIUS AND ULNA IN SUPINATION OF THE HAND.

At the ankle the tibia articulates with the astragalus, which, however, represents two of the tarsal bones grown together. This fusion to form the astragalus explains the presence of but seven tarsal bones. The large tarsal bone forming the heel, into which the tendon Achilles is attached, is the heel bone, or os calcaneum. These tarsal bones, then, connect with the metatarsal, which are in turn followed by a series of three phalanges for each toe, and two for the big toe. In the hands and feet, especially of persons who are in the habit of doing hard manual labor,

there are developed frequently at the joints small, extra bones, called sesamoid bones. The rather large knee cap is probably nothing more than such a sesamoid bone, which

Fig. 34.—THE RIGHT FEMUR FROM BEHIND.

Fig. 35.—THE BONES OF RIGHT FOOT, SEEN FROM ABOVE.

A, navicular bone; b, astragalus; c, d, os calcaneum; e, internal cuneiform; f, middle cuneiform; g, external cuneiform; h, cuboid bone; I, V, metatarsals; 1, 2, 3, phalanges.

has finally become persistent. Such sesamoid bones probably serve to lessen the friction of the tendons pulling from the joint.

THE SKULL.

The bones of the skull serve to enclose the brain and to give support to the face and its organs. The bones which enclose the brain, or cranium, are eight: the frontal, two parietals, two temporals, one occipital, one sphenoid, and one ethmoid. The bones which serve to form the face are the

two nasal bones, the two lachrymal bones, two malar bones, the upper maxilla, the two palatine bones, the lower maxilla,

Fig. 36.—FRONT VIEW OF MALE SKULL AT ABOUT TWENTY YEARS. (Allen Thomson.)

1, frontal eminence; 2, glabella, between the superciliary ridges, and above the transverse suture of union with the nasal and superior maxillary bones; 3, orbital arch near the supraorbital notch; 4, orbital surface of great wing of sphenoid, between the sphenoidal and the sphenomaxillary fissures; 5, anterior nasal aperture, within which are seen in shadow the vomer and the turbinate bones; 6, superior maxillary bone at the canine fossa—above the figure is the infraorbital foramen; 7, incisor fossa; 8, malar bone; 9, symphysis of lower jaw; 10, mental foramen; 11, vertex, near the coronal suture; 12, temporal fossa; 13, zygoma; 14, mastoid process; 15, angle of the jaw; 16, mental protuberance. In this skull there are fourteen teeth in each jaw, the wisdom teeth not having yet appeared.

the vomer, and the two turbinates. Suspended by cartilaginous threads from the temporal bone is the hyoid bone, which serves to give support to the muscles of the tongue.

It is entirely impossible to give any satisfactory descriptions, and even in good pictures, any adequate notion of the

arrangement of bones. The enumeration of the bones and the cuts here given are intended to serve only as a manual in the hands of the student who is fortunate enough to have an actual skeleton before him for study. Detailed descriptions of the individual bones is deemed unnecessary, but the detail given in the pictures, together with

Fig. 37.—THE HYOID BONE.

Fig. 38.—A SIDE VIEW OF THE SKULL.

O, occipital bone; *T*, temporal; *Pr*, parietal; *F*, frontal; *S*, sphenoid; *Tsp*, wing of sphenoid; *Z*, malar; *Mx*, maxilla; *N*, nasal; *E*, ethmoid; *L*, lachrymal; *Md*, inferior maxilla.

the accompanying names, ought to be the points which the student should verify for himself on every bone in question.

THE MINUTE STRUCTURE OF BONES.

Little need be said concerning the gross structure of bones. A mere glance will show one the difference between

Fig. 39.—THE GROSS ANATOMY OF A LONG BONE. (Humerus.)

a, medullary cavity containing the marrow; *b*, shaft of hard bone; *c*, spongy or cancellated bone; *d*, terminal cartilage.

the long bones, such as the femur or humerus, the short bones, such as those of the tarsus and carpus, the tabular bones, like the parietal bones of the skull, and the irregular bones, which do not seem to fit in any of the preceding classes. If, further, a long bone, such as the humerus, say, be examined, it is easily seen to consist of a long shaft made up of hard, dense, apparently homogeneous bone, with somewhat expanded ends, intended for articulating surfaces. Numerous little holes are visible, through which blood-vessels and nerves enter the bone. If such a bone be sawed in two a large, empty space appears through the shaft, known as the medullary cavity. It is filled in life with a yellowish substance consisting mostly of fat, called the yellow marrow. At the end the bone is seen to be cancellated or spongy. In this cancellated bone is found the red marrow, the seat of the formation of the red corpuscles of the blood. Further than this nothing can be made out as to the structure with the unaided eye. If a tabular bone such as the parietal be examined, numerous little openings into it for the entrance and exit of blood-vessels are again visible, while if it be broken it shows that it is made up of two plates, the denser

bone on the outside and an intervening layer of spongy bone called diploe. The structure of the parietal bone is

repeated in a number of the irregular bones of the body, which have on the outside some denser bone, while the interior is more or less spongy. It will be recalled that

Fig. 40.—LONGITUDINAL SECTION OF THE HEAD OF THE FEMUR SHOWING THE CANCELLED STRUCTURE AT END, AND SOLID BONE OF SHAFT. (From a photograph by Zaaijer.)

in the spongy part of all these bones, no less than in those of the long bones, red marrow occurs.

To discover the real structure of bone it is necessary to grind a bone into an exceedingly thin section, so that it may be viewed with a microscope. If such a cross section,

say from the shaft of the humerus, be taken, it is found to be not homogeneous at all, but pierced by a set of canals running mainly in a longitudinal direction, known as Haversian canals. Through these canals run blood-vessels, nerves

Fig. 41.—TRANSVERSE SECTION FROM THE SHAFT OF THE HUMERUS, SHOWING THREE HAVERSIAN SYSTEMS COMPLETE.

The Haversian canals, lacunæ and canaliculi appear black, being filled with air and debris from the grinding.

and lymphatics. Around each Haversian canal lie from several to many series of cylindrical plates, or lamellæ, between which occur in characteristic rows little openings called lacunæ. Running out from each lacuna are many divergent and branching canals called canaliculi, which connect with similar canals from the immediately surrounding lacunæ. The canaliculi of the lacunæ next to the Haversian canal open into the Haversian canal. By this system of lacunæ and canaliculi nourishment may soak from the Haversian canal through every portion of the bone. These lacunæ are in life each filled by a little corpuscle not unlike an ordinary white blood-corpuscle, called an osteoblast. Arms from these osteoblasts extend through the

canaliculi and come in contact with similar arms of neighboring osteoblasts. In this way there is really a system of direct communication between the living parts of the entire

Fig. 42.—AN OSTEOLAST IN DETAIL.

a, the wall of the lacuna where the bone corpuscle has shrunk away from it.

bone. These osteoblasts are the agents which secrete the bone substance surrounding them, somewhat like the clam secretes its surrounding calcareous shell. The bone substance, or the matrix, as it is called, appears perfectly homogeneous, but with proper reagents there may be brought to view many little fibres permeating it in all directions. These fibres, no doubt, add materially to the strength and consistency of the bone, somewhat as the hairs frequently mixed with mortar materially serve to keep that from crumbling. These fibres were named after the person who first carefully described them, and called the fibres of Sharpey. The firmness of the matrix is due to the large amount of mineral matter which it contains, there being about sixty-five per cent. of inorganic matter in bone. Of these inorganic constituents the most abundant is calcium phosphate. In small quantities there occur combinations of fluorine, chlorine and magnesia. Small quantities of calcium carbonate are present. In this matrix the osteoblasts are not merely included by chance, but remain there in order to look after the constant wear and repair of the osseous tissue. By extracting the proper ingredients from the lymph which seeps to them, they are enabled wherever either the cell itself or its arms touch, to secrete new bone,

and in this way to preclude any material disintegration of bone in any part of the body. As the bone substance is everywhere riddled, even to the smallest bits, with these osteoblasts and their ramifications to such an extent that

Fig. 43.—LAMELLÆ TORN FROM A PARIETAL BONE TO SHOW THE FIBRES OF SHARPEY, c, c. (After Sharpey.)

b, thick opaque portion of bone. a, holes where fibres had been.

the point of an ordinary pin would really cover many of them, one can understand under what thorough supervision the repair of normal bone is, and how even in the smallest and most out-of-the-way portions a disintegration or softening in any way is at once remedied. The osteoblasts when once included in these lacunæ are never able to leave them, but remain there until death or until the processes of age in later life cause many of them to apparently disintegrate and disappear. This disappearance of the corpuscles from old bones, as well as the continued calcareous depositions in it, accounts for the brittleness of the bones of old people and the difficulty with which broken portions are healed.

The Haversian canal with its series of lamellæ, lacunæ and canaliculi, is called the Haversian system. Where these systems meet, irregular bits of bone frequently fill in the space between. Around the outside of the entire bone

there is a rather strong fibrous membrane completely investing it except at the ends, called the periosteum. This is a membrane mostly of white fibres and some yellow elastic tissue, which serves to carry the blood-vessels which are to enter and nourish the bone. In the meshes of this periosteum the entering blood-vessels divide and branch, and so plunge into the bone at many different points. Immediately under the periosteum is a layer of ordinary osteoblasts. The connection of these osteoblasts with the formation of bone is mentioned further on.

The current notion that the periosteum is the thing that nourishes the bone and even produces it is correct only in so far as it carries and distributes the blood-vessels which enter the bone, and has under it the bone corpuscles which form new layers of bone. For this reason, if in any surgical operation or otherwise the periosteum is removed from the bone, the bone soon dies for lack of nourishment. The ability of the periosteum with the osteoblasts underneath it to form bone is strikingly illustrated in instances where such periosteum removed from a bone was tunneled in among muscles and in that position gradually developed a new bone. But it must be remembered that this formation of new bone was in no part a function of the periosteum itself, which is a mere connective tissue membrane, nor even of the blood-vessels which it carries in numbers, but of the osteoblasts included under it.

If some of the cancellated bone from the ends be examined in a similar way under a microscope as the section taken from a shaft, the view is quite similar, except that the Haversian systems are a little larger and their arrangement not so compact.

ORIGIN AND GROWTH OF BONE.

In the way in which bones originate in the body they are divided into two classes, called the membrane bones and the cartilage bones. Membrane bones are those bones which have never been preceded by cartilage, but have

developed directly from a membrane. A typical example of such a membrane bone is the parietal bone of the skull.

Growth of Cartilage Bones.—Cartilage bones are those bones which are preceded by cartilage which has been removed and, later, bone deposited in its place, or as commonly stated in our text-books, bones which ossify from cartilage. If the limb of a young animal be examined in embryonic life even before the cartilages have made their appearance, the following series of changes may easily be noticed:

In earliest life such a limb budding out from the body would consist throughout of perfectly similar cells, the original descendants of the primitive egg cell. Soon after, among many other changes, there might be noticed, in the place where the cartilage is to appear, to form, say the humerus, a number of cells similar to the others in appearance, which, however, begin to secrete between themselves a substance familiar to us as cartilage. In this cartilaginous matrix these cells, which we may now call cartilage cells or chondrioblasts, multiply and by a continued secretion from these the matrix of the cartilage finally results. As this cartilage is plastic, and may extend by interstitial growth, it soon comes to possess the form intended for the future bone. A membrane soon invests this cartilage except at the ends, which membrane will become the future periosteum, which now, as it surrounds cartilage, is called the perichondrium.

This membrane becomes filled with blood-vessels, and underneath it, that is between it and the cartilage, there come to lie numerous little corpuscles, the osteoblasts of the future bone. At this stage of the process no bone is yet present, there being but a solid cartilage rod of the form of the intended humerus, surrounded by the membrane. Soon after this the process commonly called the process of ossification begins.

This is generally understood to mean the turning of the cartilage into bone, but such a change in no sense takes place. Ossification really consists in the gradual removal of the cartilage and in the formation of entirely new bone. The changes which convert this cartilage into the bony humerus, as we know it, are as follows: *

A little before the process of bone formation begins, it may be noticed that the cartilage at the point of ossification becomes somewhat gritty, probably due to the deposit of extra mineral matter in the cartilage. In the case of the humerus this point is near the middle of the shaft. Soon after this, peculiar large cells burrow and absorb a passageway for themselves from under the periosteum through the cartilage until they reach the middle of the shaft. Here these large cells continue their process of dissolving and absorbing the cartilage, and so tunneling it in every direction. These large cells are called osteoclasts, or possibly more generally myelo-plaques. By the eating away of the cartilage in this way the central portion of the cartilaginous humerus is soon converted into an intricate system of tunnels, which gradually extend further and further towards the ends of the bone. The absorption of the cartilage is probably explained as due to the digestive action of the liquid which these myelo-plaques secrete. What happens to the cartilage cells themselves when their matrix is removed is not yet definitely known. According to some observers the cartilage cells, too, are absorbed; while according to other observers these cells when liberated change into bone cells, and figure in a way to be described later. In the tunnels so made, blood-vessels from the periosteum grow, and from the same place large numbers of osteoblasts follow up these channels. These osteoblasts secrete bits of bone against the walls of these tunnels, possibly not unlike the stone masonry that lines many railroad tunnels. When finally all

* As the changes in the case of this bone are, except for local differences the same for every other, this one instance may suffice to explain the phenomena of ossification wherever occurring.

the cartilage is removed and nothing but this mesh-work of masonry left, there is produced in the center of the humerus what is familiar to us as spongy bone. Be it observed, however, that this spongy bone is in no sense derived from the cartilage, but is an entirely new product, and that all the cartilage, together with its cartilage cells, has been removed. While these changes are going on in the shaft of the bone the osteoblasts under the periosteum have begun to secrete bone there, and so have surrounded the cartilaginous shaft with a fine casing of osseous tissue. Layer after layer of bony lamellæ is added until there has been formed a cylinder of bone of quite appreciable thickness, moulded right over the original cartilage. In this way the new bone receives at once the shape intended for it. While the strength of the shaft is thus added to under the periosteum, new osteoclasts, or myelo-plaques begin to remove the spongy bone just deposited where the cartilage was removed. In this way by the continued absorbing action of these cells there is soon formed an empty space, the beginning of the medullary cavity. The tunneling of the cartilage extends further and further towards the ends of the bone. These tunnels are then immediately lined with layers of bone by succeeding osteoblasts, and so the formation of spongy bone proceeds gradually towards the extremities. This spongy bone is, however, at the rear end being continually absorbed by other osteoclasts, and so the medullary cavity reaches further and further towards the opposite ends. If this continued uninterrupted and with the rapidity with which it goes on for a while, it would soon remove all of the cartilage, even to the very ends. But this stage is never reached, for while the cartilage is being continually encroached upon and removed at one end it keeps elongating above, continuing to do so until the full length of the adult bone has been reached. As the cartilages at the ends grow the periosteum creeps further and further along it and begins the deposition of bone. In this way the bony shaft follows *pari passu* the enlargement of the cartilage. Thus

it will be seen that bones grow in length really by the cartilaginous ends growing, and then the cartilage being removed from the inner side in the manner just described.

In this way not only has the entire cartilage of the shaft been removed, but as the periosteum forms more and more bone beneath itself osteoclasts begin to remove bone from the medullary cavity side, and so this cavity becomes larger and larger. The explanation of this probably consists in the fact that the first bone deposited by the periosteum is not as strong as that which is later on deposited, and so it is removed in order to avoid surplus weight. This eating away of the bone from the inner side continues for a long time, and so it happens that the medullary cavity of an adult bone may be very much larger than the piece of cartilage which originally filled it. From these statements it is clear that the bone grows in thickness only by the addition of layers around the outside by the osteoblasts under the periosteum. The older notion that a bone deposit also takes place by osteoblasts which line the medullary cavity no longer seems valid.

The encroachment of the bone into the cartilage at the end does not reach the ends of the bone as we see it in the adult specimen, but after the cartilage has grown to the size intended for the future bone, independent centers of ossification start up in these ends with processes identical with those just described. In this way the bony epiphyses, as they are called, at the ends of most long bones arise. Later on the cartilage between the epiphyses is gradually absorbed from both sides and the bone becomes continuous, or, as we say, the bone becomes "knitted." This does not take place until quite late. For instance, in the humerus the lower epiphysis unites with the shaft about the seventeenth year; the upper epiphysis about the twentieth year. In the femur the upper end is joined to the body of that bone about the nineteenth year, and the lower end becomes knitted about the twentieth year. In the fibula this knitting is still later, occurring at the lower end about the

twenty-first year, and at the upper end about the twenty-fourth year. The individual vertebræ which fuse together

Fig. 44.—PART OF A LONGITUDINAL SECTION OF THE DEVELOPING FEMUR OF THE RABBIT. DRAWN UNDER A MAGNIFYING POWER OF 350 DIAMETERS. (From Klein and Noble Smith.)

a, rows of flattened cartilage-cells; *b*, greatly enlarged cartilage-cells close to the advancing bone, the matrix between is partly calcified; *c*, *d*, already formed bone, the osseous trabeculae being covered with osteoblasts (*e*), except here and there, where a giant-cell or osteoclast (*f*), is seen, eroding parts of the trabeculae; *g*, *h*, cartilage-cells which have become shrunken and irregular in shape. From the middle of the figure downwards the dark trabeculae, which are formed of calcified cartilage matrix, are becoming covered with secondary osseous substance deposited by the osteoblasts. The vascular loops at the extreme limit of the bone are well shown, as well as the abrupt disappearance of the cartilage-cells.

to form the sacrum, and which are ossified from five different centers, unite as late as the twenty-fifth year, while the

three bones that form the os innominatum, unite about the same time. Thus we may see that the human body does not reach its skeletal maturity until about twenty-five years of age. From a hygienic standpoint this ought not to be forgotten, for loads that a man of thirty may carry without the least danger, may prove disastrous for a lad of eighteen or nineteen, in spite of the strength of his muscles.

Some interesting experiments have been made in order to determine the manner of growth of bones, by feeding young pigs madder. In this madder there seems to be a compound which colors bone in which it is deposited red. When, now, such a pig in question has for a month or two been fed with madder, and is then killed and the bone examined, it is found that there is a layer of reddish bone immediately under the periosteum and zones at the ends where the cartilage has been encroached upon. All the bone, however, next to the medullary cavity remains unstained. By taking such a pig and feeding it this madder, in alternate months, it is possible to produce characteristic rings of red and white, encircling the shaft of the bone under the periosteum and zones of red and white alternating at the extremities. That the shaft itself does not grow is easily demonstrated by driving some pointed pegs into the shaft of a living bone, and then measuring their relative distances after a certain period has elapsed. In the shaft of the bone these pegs do not separate, showing that no elongation has taken place. If, however, one of the pegs be inserted in the cartilaginous end the regular elongation appears.

The bone which is deposited under the periosteum is deposited in successive layers, much like the layers of an onion. These layers of lamellæ do not show the characteristic arrangement of the Haversian systems, as described on a former page. To explain how these circumferential lamellæ become later changed into the characteristic Haversian systems is at present no easy matter, but it is believed on good grounds that the circumferential lamellæ are actu-

ally removed piecemeal, and replaced by a new growth of bone extending into it from beneath. To state it again, it is probably the migration of the Haversian systems of the deeper portions of the bone into the outer layers, accomplished no doubt by a piecemeal absorption of these outer layers and the re-deposition of new bone, showing the Haversian system. It is possible that this change from the stratified appearance of the layers under the periosteum to the normal Haversian systems is to be accounted for on the grounds that the latter system is better adapted for the nourishment of the bone, and that possibly for physical reasons the columnar arrangement of the Haversian systems is stronger than that of the stratified lamellæ. Future investigation, however, must solve for us a number of questions still unanswered in this matter.

While the bones do not grow, as we ordinarily use that term, after the twenty-fifth year, they may change their shapes to some extent; for throughout the greater part of life there is an absorption of bone in some places where it is no longer needed, and a continued deposition in other places where added strength is desired. When bones are mechanically broken they are united by having osteoclasts first remove the dead bone from the broken ends, and then having the osteoblasts cement the pieces together with new bone, which may in some cases even be preceded by a formation of cartilage. This removal of the dead bone is probably identical in process with the removal of the cartilage and bone regularly occurring in their growth.

Such bone absorption occurs in the milk dentation and also explains the occasional loosening of the permanent set of teeth, owing to the removal of the cement, which is really bone.

While in the long bones there is usually a single center of ossification, near the middle of the shaft, with later ones to form the epiphyses, they may be much more numerous in irregular bones. Thus in the irregular sphenoid bone

there are as many as eight different points at which the process of ossification begins.

Growth of Membrane Bones.—The second class of bones comprises the membrane bones. As previously stated, these are bones which are never preceded by cartilage. A typical illustration of such a membrane bone is the parietal. Preceding this bone in early life there is just an ordinary connective tissue membrane, containing no mineral deposit

Fig. 45.—PART OF THE DEVELOPING PARIETAL BONE OF A FOETAL CAT. (After Schäfer.)

sp, bony spicules, with some of the osteoblasts imbedded in them, producing the lacunæ; *ost*, osteoblasts partly imbedded in the newly formed bone; *of*, osteogenic fibres prolonging the spicules, with osteoblasts between them and applied to them; *a*, granules of calcareous deposit between the osteogenic fibres; at *b* the granules have become blended, and the matrix is clearer; at *c* a continuity is established between the two adjacent spicules.

of any kind. Portions of this membrane are still evident on the skull of a new-born child, and are familiar as the fontanelles. In the meshes of this membrane osteoblasts find their way, which begin at once to secrete over it the mineral matter of the bone. By this continued secretion of

bone in and around this membrane the fully formed parietal comes to be. While not strictly analagous, the primitive membrane might be compared with the periosteum, next to which, as in the long bone, occurs the mineral deposit.

CHEMICAL COMPOSITION OF BONE.

The chemical composition of bone has been referred to. Human bone consists of sixty-five per cent. inorganic matter and thirty-five per cent. organic matter. This organic matter consists of a matrix called osseine, with which the inorganic constituents so combine that even under a microscope it looks homogeneous. This osseine is easily changed by boiling it, into the familiar gelatine. In fact, much of the gelatine of commerce is derived from the bones of slaughtered animals, and an integral ingredient of the soup made by boiling a soup bone is gelatine. It figures further in a variety of roles in the preparation of foods and desserts familiar to every household cook. The mineral salts are mainly calcium phosphate and calcium carbonate, and from this mineral part of bone-earth much of the phosphorus of commerce is derived. By placing a bone in weak hydrochloric acid it is possible to dissolve out the mineral salts and leave nothing but the organic portions. Such a bone is soft and flexible. On the other hand, it is possible to remove the organic portion by what is known as calcining the bone in a hot fire, which burns up all the organic matter. In this way the bone-dust of commerce is made. When the organic matter of a bone is not completely burned up, but charred, it forms the familiar bone-black used in many ways in the arts and in commerce, especially in the purification of sugar.

HISTORICAL.

As early as 1736 Nesbitt showed that some flat bones were formed perfectly independently of cartilage, and even insisted that the cartilage was often destroyed in cases where it did precede the real bone structure. The primi-

tive cartilage he explained as a mere temporary substitute used to mould the shape of the succeeding bone, but as he was unable to actually demonstrate his views as they are now demonstrated with the microscope, they were but little credited until Sharpey, in 1846, made clear beyond all question the manner of the formation of bone and the replacement of the cartilage.

Cartilages.

The second kind of the supporting tissues comprises the cartilages, familiar under the more common name of gristle. Cartilage differs from bone in the fact that the cells which fill it are not branched, but smooth, and the matrix does not possess a system of canals and canaliculi. As a rule the mineral ingredients are much less in proportion than in bone, although in older cartilages a calcification takes place which results in giving to the cartilage as

Fig. 46.—HYALINE CARTILAGE FROM THE LOWER END OF TIBIA. (After Schäfer.)
a, b, c, different arrangement of cell groups; d, layer of calcified cartilage; e, bone.

great a proportion of earthy matter as bone possesses. But such calcified cartilage is structurally entirely different from bone.

Three fairly distinct types of cartilage occur, the hyaline, the yellow elastic and the white fibrous. In the hyaline cartilage, as the name suggests, the matrix seems entirely homogeneous; that is, devoid of any fibrillation. In this structureless material the cartilage cells are imbedded. A view held by some histologists that this apparently structureless matrix is permeated by a system of very fine canals, lacks verification. Such hyaline cartilage is found regularly at the ends of bones, where a smooth, articulating surface is necessary. The yellow elastic cartilage differs from hyaline in having the matrix made up of densely packed yellow elastic fibres, in the close meshes of which the cartilage cells are lodged. Such cartilage occurs in the ear and the

Fig. 47.—YELLOW ELASTIC CONNECTIVE TISSUE FIBRES. (After Sharpey.)

Fig. 48.—YELLOW ELASTIC CARTILAGE FROM THE EAR.

tip of the nose, and is peculiarly well adapted to admit slight alterations in position or form. The white fibrous cartilage, as the name suggests, is composed of a matrix of closely pressed white fibres, with the contained cartilage cells packed between them. Such cartilage is found in many places as disks between articulating bones; it binds together contiguous bones forming connecting fibres between

them, and in still other cases it lines bony grooves in which tendons of muscles glide. Such cartilage is pre-eminently

Fig. 49.—WHITE FIBROUS CARTILAGE FROM AN INTERVERTEBRAL DISK. (After Schäfer.)

fitted for positions where strength and rigidity are required. The cartilages shade off insensibly and without any sharp line of demarkation into the connective tissues proper, that

Fig. 50.—TRANSITION FROM CARTILAGE.

a, through the intermediate form *b*, to connective tissue, *b*, on the right.

tissue which pervades all the organs of the body and is the framework of every structure.

Connective Tissues Proper.

Of these connective tissues proper, two varieties occur. The elastic is composed of thick, wavy, yellow elastic threads, which frequently branch. This tissue is found in those parts of the body where elasticity is desirable, as for instance, in the walls of the arteries and veins, and is to a large extent the prevailing tissue in the lung. The white fibrous tissue, on the other hand, is composed of bundles of smaller, straighter white threads possessing little or no elasticity. This tissue is especially well exhibited in the tendons and

gives to these their strength. As far as the fibres are concerned, there is but little difference between the yellow elastic and the white fibres of cartilage, and the corre-

Fig. 51.—CONNECTIVE TISSUE CORPUSCLES. (After Schäfer.)

sponding ones of connective tissue, their classification into cartilage or connective tissue being determined rather by the closeness of these threads and the shape of the corpuscles which are included. In the cartilages, on account

Fig. 52.—FIBRES OF AREOLAR TISSUE.

of the firm texture, the cells are round and have little latitude to move about. In the connective tissues, on the

other hand, the meshes being much more open, the enclosed cells become much branched and have the power to move about. Such wandering connective tissue corpuscles are not always easily distinguished from wandering blood corpuscles. While in the case of cartilage the yellow elastic varieties and the white fibrous varieties are found tolerably separate, in the connective tissues we frequently find both making up the framework of the structure in question. Such a mixture of yellow elastic and white fibrous tissue is called areolar tissue, and is particularly well exemplified in the connective tissue under the skin.

Humors.

A final kind of supporting tissues frequently classed with the connective tissues proper are the humors of the eye. In these the matrix has never become hard with mineral depositions, has never developed fibres in it of any kind, but remains almost perfectly liquid. The connective tissue cells which have formed these humors, later on atrophy and practically disappear, leaving this structureless matrix behind.

FORMATION OF CARTILAGE AND CONNECTIVE TISSUE.

In their manner of formation all the supporting tissues are alike. They are not made by a direct differentiation of cells into these tissues, but, as stated once before, are formed as a secondary product by the cells. In the case of bone, this deposition has been treated at length. In the remaining supporting tissues the origin is quite similar, save that the cartilages and connective tissues are not added continually from the outside, but grow throughout the entire substance; that is, it is a growth by intussusception. The cartilage cells in the matrix retain the power to divide, and new cells formed by such division separate by the secretion of more matrix between them. In the case of the yellow elastic cartilage this has been specially worked out. Here the matrix is first deposited in the form of little

granules, probably secreted or excreted by the cartilage cells, which granules later on in some way not yet understood, fuse, forming the characteristic fibres. While most cartilages have a membrane around them called the perichondrium, such a membrane does not figure in any way as it does in the formation of bone, but is here *merely* an enveloping membrane supplied, of course, with blood-vessels.

Fig. 53.—DEVELOPMENT OF ELASTIC TISSUE BY THE DEPOSITION OF ROWS OF ELASTIC GRANULES, *g*, FINALLY FUSING INTO A PLATE-LIKE EXPANSION OF ELASTIC SUBSTANCE INDICATED AT *P*. (After Ranvier.)

The method of origin of yellow elastic tissue just cited, probably does not differ from the manner in which the connective tissues proper and the humors arise, save that in these the corpuscles which have produced them may actually wander out and leave nothing but their product behind. The supporting tissues being thus not directly composed of cells, possess no physiological activity, and when once formed probably remain entirely unaltered during life. The various forms do not differ much in chemical composition, except the yellow elastic, all yielding when boiled, a variety of gelatine. Their similar nature is further indicated in the fact that they replace each other easily. Thus, cartilages are replaced by bone, and broken bones are sometimes cemented together by the formation of cartilage.

HYGIENE OF SUPPORTING TISSUES.

In reference to the supporting tissues, little need be said from the standpoint of their hygiene. It is, of course,

apparent that in young persons the food should contain sufficient amounts of mineral salts, otherwise the bones will not acquire their intended hardness. Milk is peculiarly adapted for this, containing quite a large amount of earthy matter. It not infrequently happens that children, in spite of an apparently rich diet, are really starving for want of the mineral matters which are needed to give consistency to these supporting tissues. The final hygienic recommendation that no unusual strains of any kind shall be placed upon any of them while they are in their formative period, is too plain to need further comment.

JOINTS.

The supporting tissues not only serve to give form and outline to the body, but in the case of bones they serve to make a system of levers to accomplish the various movements of which the body is capable. To permit such movements, bones are articulated together to form more or less movable joints. In the body there are found four kinds of movable joints. They are, first, the gliding joints; second, the pivot joints; third, the hinge joints, and fourth, the ball-and-socket joints. In addition to these movable joints, bones articulate in such a way as to preclude motion. Instances of such articulation are plain in the bones of the skull, where the bones remain separate until the skull has reached its mature size. Such articulations are called sutures.

In the gliding joints a number of bones glide over each other to such an extent as to permit quite a little motion. Instances of such joints are in the wrists and ankles. Here the carpal and tarsal bones gliding over each other permit all the different motions of which the wrist and ankle are possible. There are but two instances of pivot joints in the body. The plainest instance is the joint between the atlas and the axis, where the odontoid process of the axis forms the pivot, around which the atlas rotates. A second illustration is in the case of the forearm, where, by the peculiar

gliding motion of the radius at the elbow, the hand may be pronated and supinated by having the radius turn on the ulna as a pivot. The hinge joints occur in greater number, being found in the elbow, the knee, and in the phal-

Fig. 54.—ARTICULATIONS OF THE PELVIS AND HIP-JOINT, SEEN FROM BEFORE. THE ANTERIOR HALF OF THE CAPSULAR LIGAMENT OF THE LEFT HIP-JOINT HAS BEEN REMOVED, AND THE FEMUR ROTATED OUTWARDS. (Allen Thomson.)

1, anterior common ligament of the vertebræ passing down to the front of the sacrum; 2, ilio-lumbar ligament; 3, anterior sacro-iliac ligament; 4, placed in the great sacro-sciatic foramen, points to the small sacro-sciatic ligament; 5, a portion of the great sacro-sciatic ligament; 6, anterior ligament of the symphysis pubis; 7, obturator membrane; 8, capsular ligament of hip-joint; the figure is placed on its ilio-femoral band; 9, upper part of the divided capsular ligament of the left hip-joint near the place of its attachment to the border of the acetabulum; 10, placed on the os pubis of the left side above the transverse ligament of the acetabular notch. The head of the femur is withdrawn partially from the socket, so as to show the interarticular ligament stretched from the transverse ligament.

anges of hand and foot. The joint which seems capable of giving the greatest latitude of motion, is the ball-and-socket joint, examples of which are the joints at the shoulder and at the hip.

In order to make these articulating surfaces as smooth as possible, bits of cartilage cover the ends of the bones. These are covered next to the joint by a delicate membrane

called the synovial membrane, which secretes a fluid known as the synovial fluid, intended probably as a kind of lubricant to reduce the friction to a minimum. To make these

Fig. 55.

Fig. 56.

Fig. 55.—RIGHT KNEE-JOINT, FROM THE INNER SIDE AND ANTERIORLY. (Allen Thomson.)

1, tendon of the rectus muscle near its insertion into the patella; 2, insertion of the vastus internus into the rectus tendon and side of the patella; 3, ligamentum patellæ descending to the tubercle of the tibia; 4, capsular fibres forming a lateral ligament of the patella prolonged in part from the insertion of the vastus internus downwards towards the inner tuberosity of the tibia; 5, internal lateral ligament; 6, tendon of the semimembranosus muscle.

Fig. 56.—THE LIGAMENTS OF THE WRIST JOINT, DORSAL VIEW.

joints firm and preclude the possibility of displacement, they are wrapped with a series of ligaments extending from one bone to the other, so as to make impossible the relative displacement of the articulating surfaces.

CHAPTER VII.

MUSCLES AND PHENOMENA OF CONTRACTION.

Probably the most striking characteristic of any living body is its ability to move. But this power of motion is by no means a property of all living things. The entire realm of plants, with exceptions of course which need not concern us here, is devoid of the power of actual movement, and there are some animals whose ability to move from place to place is entirely wanting. The movements of our bodies are caused by the contraction of organs familiar to every one as the muscles. There are, however, in the body structures other than the muscles which possess this power to a certain extent. Thus, many of the varieties of white corpuscles, such as the white blood corpuscles, cartilage cells, connective tissue cells, are able to move from place to place. Such locomotion is described as amœboid. The power of active movement also occurs in ciliated cells which are found lining the entire respiratory system, with the exception of the pharynx and the internal lung cells, and which occur also in the internal genital ducts. Such cells consist of a main body which shows no power of motion, but is continued at one end into a number of thread-like prolongations, which have the power of moving rapidly backwards and forwards. The expulsion of the phlegm from the respiratory passages up into the mouth is accomplished by such ciliated action. It is interesting to observe that all the cilia of a membrane seem to move in harmony, the movements of the cilia sweeping across the surface like waves of moving grain through a wind-swept wheat field. In the internal genital ducts they serve to

propel the re-productive elements. The real organs of movement are, however, the muscles. A careful examination of the entire muscular system of the body shows at once three tolerably distinct kinds of muscles. First, the voluntary or skeletal muscles; or, on account of their microscopic appearance to be described later, cross-striated muscles. Second, the involuntary, visceral or plain muscles. Third, the muscles which form the heart, and which differ materially from both of the preceding, and occupy from an anatomical point of view an intermediate position.

Voluntary Muscles.

As the name indicates, these muscles are under the control of the will. This is, however, not absolutely true, as there are a number of muscles over which the control of the will has been lost. Thus, there are some muscles of the ear which, if they could be used, would serve to move that organ, but the power to move them has been entirely lost. That nearly all of these muscles are attached to bones has given them the name of skeletal muscles. But there are exceptions to this as well. Thus the circular muscles enclosing the mouth or the eyes, are not attached at all to any bone, and yet are voluntary in the highest degree. The real classification is based upon their minute structure, and in this all agree in showing under the high power of the microscope peculiar cross striations to be discussed later.

TYPES OF VOLUNTARY MUSCLES.

A typical muscle is composed of a thick, central portion called the belly, which tapers at each end into a thick string of white fibrous tissue familiar as the tendon. From this type, however, there are many deviations. Thus the muscle which serves to bend the arm forward, ends at the shoulder in two tendons instead of one. This has given the name of biceps to this muscle. Immediately under the

arm lies the muscle which serves to extend the arm, which

Fig. 57.—SHOWING THE SUPERFICIAL MUSCLES OF THE RIGHT ARM, FROM BEFORE.

1, 1', pectoralis major; 2, 2', deltoid; 3, 3', 3'', biceps; 4, 4', brachialis anticus; 5, 5', triceps. Numbers from 6-17 refer to muscles and tendons of fore-arm and hand.

ends in three tendons at the shoulder, and is called the triceps. Then again there are muscles which have a tendon in the middle, thus dividing the muscle into two portions. Such a muscle is called a digastric muscle, that is, has two bellies. Sometimes even more than two occur, when the muscle is called a polygastric muscle. Instances of such polygastric muscles are found in the anterior abdominal wall. Closer examination of a typical muscle will show it divided up into bundles separated from each other by intervening connective tissue. On a cross section of a muscle these bundles would appear as irregular areas, and are familiar to every one in the characteristic appearance of a piece of lean beefsteak. This connective tissue not only extends through the muscle, dividing it up into bundles which are called fasciculi, but envelopes the entire muscle. It serves to carry the nerves and blood-vessels through the muscle, and is called the perimysium.

HISTOLOGY OF VOLUNTARY FIBRES.

Fibrillation.—For a more detailed study the microscope must be called to aid, and it is then seen that the fasciculi are divided into still smaller bundles, and that the smaller bundles are finally composed of the ultimate fibres. These muscle fibres all run in the same direction, which accounts for the splitting observed on any piece of boiled beef. If

such a small bundle be teased under the microscope into its

Fig. 58.—SEVERAL VOLUNTARY MUSCLE FIBRES. (After Sharpey.)

a, end view of fasciculus; *b*, *b*, individual fibres; *c*, a fibre splitting into longitudinal fibrils.

ultimate fibres, the following points may be noticed concerning their finer structure:

Striation.—The fibres appear cross-striped. This is not due, however, to markings running on the outside of a

Fig. 59.—PORTION OF A HUMAN MUSCULAR FIBRE SHOWING THE ALTERNATE LIGHT AND DARK BANDS, AND IN THE LIGHT BAND THE MEMBRANE OF KRAUSE. (After Sharpey.)

Fig. 60.—TWO VOLUNTARY FIBRES. (After Gegenbaur.)

n, nuclei under sarcolemma; *s*, sarcolemma visible where the fibre is torn.

muscle, but it is due to the fact that a muscle fibre is com-

posed of alternating light and dark disks, somewhat like a stack of coin might be composed of alternate copper cents and silver dimes. If a crushed portion of a fibre be examined it is possible to make out a delicate covering extending entirely around the fibre, known as the sarcolemma. In this sarcolemma lie the more or less semi-liquid contents, which exhibit the striation referred to.

Nuclei.—Scattered along the fibre here and there, and lying immediately underneath the sarcolemma, are nuclei.

Measurements of an Individual Fibre.—Measurements of these fibres in an adult muscle give a length of from one-half inch to an inch and a half, and a width of about one five-hundredth of an inch. Little floating gossamer threads cut in lengths of an inch or more may serve to give us an idea of their actual size. It will be seen from their length that an individual muscle fibre does not run the entire length of a muscle, as many muscles are five, six, or more inches in length.

Attachment to Tendons.—A delicate fibril from the tendon may be traced to the end of a muscle fibre where it is directly cemented to the sarcolemma. An older view that the tendons are but the connective tissue of a muscle extended, is no longer tenable. Whether such tendon fibrils run to both ends of all fibres, is still a matter of question. Some histologists claim two or more muscle fibres may be cemented end to end; others again that the muscle fibres are twisted and intertwined with each other somewhat like threads in a rope, and that tendons attach themselves merely to the outermost fibres. The probability of the matter, however, is that in the majority if not in all cases each individual fibre receives at both of its ends a delicate little fibril from the tendon, which fibril is directly and firmly cemented to its sarcolemma. This would make each individual muscle fibre in reality a separate muscle.

Blood Supply.—A voluntary muscle is quite vascular, each fibre being invested with a capillary net-work almost

along its entire length. These capillaries, together with the

Fig. 61.—SHOWING THE MANNER IN WHICH THE CAPILLARIES ARE SUPPLIED TO THE VOLUNTARY FIBRES. (E. A. S.)

nerves, are carried by the connective tissue perimysium, which wraps more or less completely each individual fibre.

Nerves.—Each muscle fibre is connected with a nerve. The nerve penetrates the sarcolemma and then has its axis

Fig. 62.—MUSCLE FIBRES FROM A LIZARD TO SHOW THE MANNER OF TERMINATION OF THE MOTOR NERVE IN THE SO-CALLED "END ORGANS." (After Kühne.)

a, side view; *b*, surface view of end organ.

cylinder expand into a broad plate-like structure known as the muscle plate, or the nerve plate. In this nerve plate occur numerous nuclei. This nerve plate is probably nothing more than the expansion of nervous protoplasm by which the contact between nerve and muscle is made the more intimate.

Color.—Ordinarily voluntary muscles appear red. Exceptions to this are, however, familiar to us all in the case of the breast meat of domestic birds, which is white. The redness of ordinary muscle is due to its containing traces of hæmoglobin, which it has probably derived from the continued coursing of the blood in such large quantities through its substance. Muscles which are not much used and which, therefore, have their blood supply much reduced, are white. Thus in wild birds which use their wings in continued flight, the breast muscles also are dark. Whether this hæmoglobin is contained in the muscle for a specific purpose, or as a mere accidental coloring, caused by the circulating blood, is not clear. Possibly it may enable the muscles to store up in themselves for ready use, a small reserve supply of oxygen.

Growth of Muscle.—The dimensions of a muscle just given are by no means invariable. In fact, the individual muscle fibres actually grow in size for a long time, being many times larger in an adult than in a very young child. The growth of muscle, resulting from continued properly directed muscular exercise, such for instance as with the blacksmith in the use of his arms, increases the size, and so of course, strength of the individual muscle fibres already formed. Reasoning in an opposite direction, the apparent atrophy of an unused muscle may be due to a peculiar shrinking of the individual muscle fibres rather than a direct absorption of them. But it seems probable that new muscle fibres may also arise after birth. There are found scattered throughout the muscular substance small spindle-shaped cells, designated as muscle cells, or more frequently

on account of their shape, spindle cells. These cells when occasions seem to demand elongate, their nuclei multiply, the external layer develops the sarcolemma and the interior protoplasm, at first structureless, receives gradually the characteristic cross markings. These cross marks seem to appear first toward the outside, and later on extend through the middle. The nuclei at first distributed through the protoplasm take their position under the sarcolemma, and in this way a new muscle fibre has been produced. A second method of muscle formation is claimed, in which the new fibres arise by a longitudinal splitting of old ones. There is no doubt but what under the microscope such splitting fibres may be occasionally seen, but whether these are fibres in process of formation, or whether they may not be fibres that are undergoing degeneration, is a question still unsolved.

THE FINER STRUCTURE OF THE MUSCLE FIBRE.

The histological points mentioned so far may be made out without any question by any good observer possessed of a good compound microscope. But when we have seen the muscle composed of alternating light and dark bands, it has not yet been made out to what kind of a structure this appearance is due. On account of the extreme minuteness it is difficult to establish the ultimate structure very plainly, so that what is given in explanation of its finer anatomy is to a large extent theory.

A single fibre is easily seen to consist of still finer fibrils, as is evidenced by the fact that the ends of a fibre will fibrillate out into delicate fibrils, much like an ordinary twisted rope when its end is unwound. These finer threads are called fibrils, and bundles of them are believed to make each individual muscle fibre. But when subjected to certain chemical agents a muscle fibre may also be made to split horizontally into small disks somewhat like the stack of coin referred to, might be thrown over and fall into the individual pieces. This would seem to show that the fibrils

themselves are made up of component pieces, in some way attached end to end to make up the entire length. These component parts of each fibril are called the muscular units or the sarcomeres. When the muscle fibres break up into these disks the line of cleavage runs through the middle of the light band. With very high powers there may be discerned at this point a little darker line, which is probably a membrane, and has been called Krause's membrane. In the longitudinal splitting of the fibre into the fibrillæ, such as a specimen of muscle hardened in alcohol readily does, the lines of splitting seem to be in a peculiar inter-columnar substance which binds the individual fibrils together.

From these two manners of breaking up it can easily be seen that the individual sarcomere is that portion of a fibril which extends from the middle of one light band, or from Krause's membrane, to the middle of the next white band. It is, therefore, light at both ends and contains its dark band in its middle. These sarcomeres, lying in even rows, give to the entire muscle fibre the banded appearance. The light material next to Krause's membrane seems to be a thin, active kind of protoplasm called hyaloplasm. The dark band in the middle really consists of two dark bands separated through the middle by a light band called the band of Hensen. These dark bands, as may easily be seen by referring to the diagram, have little comb-like projections extending up and down, which next to the band of Hensen are united together on each side to a common base. Whether these prongs or teeth are solid, or whether they are hollow tubes, cannot be determined. They probably consist of a firmer kind of protoplasm, and are in each sarcomere called the sarcosome. The transparent columnar substance, which seems to cement the individual fibrillæ together, is of a similar kind of protoplasm called sarcoplasm. Thus the individual sarcomere would have hyaloplasm at its ends, have the sarcosome or dark portion in the center, and be connected with neighboring sarcomeres by the intermediate sarcoplasm.

When a muscle contracts it may be seen that the white band becomes narrower, but that the teeth-like projections of the sarcosome become pushed further apart and dis-

Fig. 63.—DIAGRAM OF A SINGLE SARCOMERE.

A, in relaxed condition; *B*, in contraction; *K*, *K*, membrane of Krause; *H*, membrane of Hensen; *S*, *E*, the darker sarcous element.

tended. The phenomena of contraction according to this view are therefore explained in this manner. When a nervous impulse reaches the muscle directing it to contract, in some way yet entirely unknown, the hyaloplasm by its activity flows in between the prongs of the sarcosome and distends these. In this way each sarcomere is slightly shortened. The multiplication of this shortening through all of the sarcomeres that make up a muscle fibre produces a movement of the entire muscle. Whether this hyaloplasm forces itself in between these prongs, or whether it distends the sarcosome by flowing into these prongs, which in the latter view would be hollow, is not known. While this serves in a physical way to make clear to us the real manner in which a muscle fibre shortens, it leaves as unanswered as before what causes the hyaloplasm in this active way to flow into the sarcosome and bulge it out laterally, thus shortening the long diameter of the fibre.

Plain Muscular Tissue.

Plain muscular tissue also is composed of fibres; but these fibres are very much smaller than those of voluntary muscular tissue, and possess no cross markings whatever. They are so much smaller than the voluntary that on an average the length of an involuntary is less than the width of a voluntary. These plain muscle fibres are about one

six-hundredth of an inch in length and very narrow, resembling elongated spindles. They seem to show a very faint longitudinal striation, and possess near their center a very evident nucleus. It is impossible to establish a cell wall, like a sarcolemma, though probably enveloped with a dark, denser layer. They are never joined to tendons, but are cemented together to form sheets of muscle. Each muscle fibre is probably supplied with its own nerve; but in this case the nerve has no end plate, but after encircling the fibre once or twice ends abruptly in the nucleus. They are not very vascular, and in cross-sections of involuntary muscular tissue, the capillaries of which have been injected so as to make them readily visible, there may be as many as twenty-five or thirty rows of plain cells between neighboring capillaries.

Fig. 64.—INVOLUNTARY MUSCLE FIBRE CELLS, FROM A HUMAN ARTERY. (After Kölliker.)
a, nucleus; *b*, a fibre treated with acetic acid to render it more transparent.

These cells have the power of shortening their long axis, but do not possess to any such extent as the voluntary muscles the ability to contract quickly or energetically. They are peculiarly well adapted to the visceral organs, where it is evident that the movement ought to be very slow, gradual and measured. Examples of this tissue may be found in the walls of the stomach and intestines, in the

walls of the arteries, around the finer divisions of the bronchial tubes, and in numerous other places.

Cardiac Muscle.

The third kind of muscular tissue occurs only in the heart. The fibres in this case are cross-striped, very similar to the voluntary. They are not quite as wide as the voluntary, but are very much shorter, a typical heart fibre being usually only about twice as long as it is wide. It possesses near its center an evident nucleus, in which no doubt, the nerve ends. There are no tendons, but the cells are cemented together in bands of fibres. Very frequently these cells are branched, a property possessed by neither of the other kinds of fibres. Because of this cross-striation and its size it is evident that it is an intermediate

Fig. 65.—SIX CARDIAC MUSCLE FIBRES. (After Schäfer.)

b, c, showing branching of cells.

kind of muscle possessing some of the properties of both, and therefore peculiarly well adapted for use in the heart, where much greater energy of contraction is desired than in the ordinary involuntary muscles.

The Chemistry of Muscle.

The muscles possess about seventy-five per cent. of water, traces of various mineral salts, bits of grape sugar,

and a peculiar kind of muscle sugar called inosit: further, traces of hæmoglobin, whence their color, bits of organic compounds such as kreatin, which will be discussed further in the chapter on excretion, and finally the important substance, muscle albumen. Just in what form this muscle albumen is in a living muscle it is impossible to determine, for in order to investigate the albumen it is, of course, always necessary to destroy the vitality of the muscle. If, however, perfectly fresh muscle be taken and then cooled almost to the freezing point, then cut into small pieces and the liquid pressed out through a cloth, there may be filtered out in this way a slightly yellowish-colored fluid called muscle plasma. This muscle plasma at ordinary temperatures coagulates much like the blood, and soon presses out of itself a serum much like a blood clot would, which serum is called muscle serum. The substance, which forms the solid portion of the clot, is familiar to all students of physiology under the name of myosin. This myosin is insoluble in water, but soluble in common salt solutions, and also soluble in dilute acids. When dissolved in dilute acids it is changed into syntonin, which is, therefore, in reality merely an acid solution of myosin. The blood plasma which has been pressed out of the clot contains several albumens, the principal one being ordinary serum albumen.

The nutritive value of muscles is derived, to a large extent, from these albumens. As most of them are, however, insoluble in water and easily coagulated by heat, but little of the albumens is removed by boiling. The mineral salts and the flavors are of course easily extracted by boiling water, and so may give to the liquid quite a strong taste, which may mislead the person into the belief that the strong taste is an evidence of its nutritive value. It is well to bear this in mind, as attempts are frequently made to nourish people on variously prepared soups and broths, in the belief that the boiling of the meat has extracted from it its nutritive ingredients. A little of the albumen may possibly thus be extracted, but the nutritive property of it is

obtained only in the digestion of the muscle substance itself. Special preparations of broth in which the muscle substance has been at first digested artificially, and thus made an ingredient of the broth have, of course, their full nutritive value.

Elasticity.

The ordinary muscles possess to some extent an elasticity which enables them when they are stretched by any weight to return to their former position as soon as the stress is removed. Naturally in the body all muscles are slightly stretched, even when entirely relaxed, for a muscle cut from one of its connections at once draws up and becomes materially shorter. This is one of the dangers accompanying the fracture of a bone, for as soon as the controlling action of the bone is destroyed the muscles pull themselves together, and so the ends of the bone may be materially displaced. The advantage of having the muscles on a stretch all the time is, that as soon as they begin to contract they begin to pull upon the bones at once and no time or energy is lost in first pulling up any slack of the muscle itself.

Physiology of Muscular Contraction.

Thus far the muscle has been considered as an inert structure, and all that has been said would apply to a dead muscle as well as one still living. But living muscles possess the property to contract when they are properly stimulated.

MUSCLE STIMULI.

The usual stimulus to usher in a muscular contraction is a nerve stimulus, but it may be stimulated in other ways. First, by mechanical stimuli: Sudden pressure, tearing, pricking, etc., produce each time a contraction of the affected muscle. Second, thermal stimuli: A sudden change of temperature causes the muscles to contract. The limits of such changes are from almost freezing up to about one hundred and ten degrees. Above and below these tem-

peratures the muscles cease to react. Third, chemical stimuli: A number of chemical agents will stimulate the muscles. Such agents are fumes of nitric oxide, sulphur dioxide, hydrochloric acid, but especially ammonia gas. Fourth, electrical stimuli: A current of electricity may in different forms induce the muscles to very vigorous activity, and one of the best worked-out chapters on muscle physiology is its reaction to electrical stimuli.

The question whether these stimuli affect the muscles themselves, and not the nerves in the muscles, can be definitely answered by saying that the stimuli affect the muscles themselves directly. For instance, ammonia stimulates the muscles, but does not affect the nerve. Still again some muscles, for instance the sartorius of the thigh, have no nerves in their ends, yet the muscle there may be stimulated to contraction. The best proof is, however, that furnished by the South American poison called curare. This curare lames the motor nerves, but a muscle with such a lamed nerve will still react to all of the preceding stimuli. This curare is used by many of the South American Indians in their chase and warfare. The end of the arrow is impregnated with the curare, and when the arrow is introduced into the flesh of an animal it drops down motionless to the ground. Its circulation and all of its sensory nerves are left intact, but there is a complete paralysis of all voluntary action. The animal of course dies by suffocation, being unable to move the muscles of respiration.

A SINGLE CONTRACTION.

Having now called attention to the stimuli which produce muscular contraction, a closer study of such a contraction itself naturally follows. If in order to study it more advantageously, a frog's muscle be entirely cut out from the body and then suspended from a hook, it may still be made to contract, and on account of its isolation, the phenomena of such a contraction much better studied. Usually a piece of nerve running to the muscle is left connected with it and

the stimuli are applied to the nerve, and through this the muscle induced to contract. If now such a muscle makes a contraction, the same occurs with such rapidity that to the unaided eye it seems but a rapid shrinking and a return to its former position. If, however, the lower end of the muscle be fastened to a lever, and this lever be made to write on a drum revolving at a known speed, the contraction will pull the muscle and consequently the lever up, and a curve will be described on the revolving surface. On this curve the various phenomena are then at leisure determinable. The arrangement for such a demonstration may be seen in the accompanying diagram.

Fig. 66.—ARRANGEMENT FOR SECURING MYOGRAMS.

P, the moving recording surface, which by the projection at *d* opens the circuit in *K* at *c*, and so induces a break current in *p* which passing through the muscle stimulates it. In this way the moment of stimulation is determined exactly, it being the moment of contact of *d* with *c*. The curve is then recorded as in figure.

If now the exact moment be noted at which the impulse reaches the muscle it is found that the muscle does not contract at once, but that there is a short period after the impulse reaches the muscle before it begins to shorten. This period is about one-hundredth of a second, and is called the *latent period*. During this period the nervous impulse has probably originated molecular changes in the muscle preparatory to the contraction. The latent period is succeeded by a steady contraction of the muscle to a maximum, followed by the relaxation of the muscle to its original position.

This movement up and down occupies about nine-hundredths of a second, making the entire time about one-tenth of a second. Just what these molecular changes in the

Fig. 67.—CURVE OF A SINGLE CONTRACTION.

R, *a*, the latent period; *a*, *b*, the gradual contraction to a maximum; *b*, *c*, the somewhat more sudden relaxation; *c*, *d*, a slight rise owing to the inertia of the recording lever, and having nothing to do with the muscle contraction itself.

muscle are, which occur during the latent period, it is impossible to tell, but it is interesting to note that by means of a galvanometer (an instrument for detecting currents of electricity) electrical currents are indicated in the muscle running from the parts furthest removed from the nerve to the part directly stimulated by the nerve. These currents are called the currents or waves of negative variation. What meaning these currents have which flow in a muscle during the latent period is not known, but they are external evidences of complicated molecular changes in the muscle substances itself, which make possible the succeeding contraction. Such a contraction which follows a single stimulus is called a simple contraction. Such a simple contraction occurs, as long as the vitality of the muscle is left intact, as often as a stimulus is applied. If, however, the stimuli are applied so rapidly that the second stimulus enters the muscle before the relaxation from the first stimulus has occurred, the muscle contracts still more. It is, so to speak, a superposition of the second contraction upon the first. Such a superposition does not, however, go on indefinitely; that is, there cannot be super-imposed a third onto a second, or a fourth onto a third indefinitely, for soon a maximum is reached beyond which, no matter how many stimuli are sent in, the muscle will not contract.

TETANIC CONTRACTIONS.

But with very rapidly entering stimuli the muscle remains in one spasmodic contraction. Such a continued and uninterrupted contraction is spoken of as a *tetanus*. All the contractions of muscles caused by the will are such tetanic contractions, for the impulses sent along voluntary paths to our muscles are sent at the rate of about *ten* per second. The fact that a voluntary muscle receiving impulses at such a constant rate does not remain in one continuous and constant contraction, is due to the fact that although the rate of the stimuli remains the same, the force of these stimuli may vary, and so the force of the contraction varies accordingly.

THE WAVE OF CONTRACTION.

When a stimulus reaches a muscle the entire muscle does not begin to contract at once, but the contraction proceeds in the form of a wave, beginning at the point where the impulse enters and extending to the opposite ends. Somewhat like a wave in a trough of water caused by the introduction of a pebble, starts at the point where the pebble strikes it and proceeds from this point in opposite direction to the ends of the trough. That is to say, the part of the muscle next to the nerve begins to shorten, and then in consecutive order portions further away from it follow. This wave of contraction can be easily noticed on a muscle as a little swelling which runs from the insertion of the nerve to the opposite ends. This rate has been measured, and is in the living muscle (not cut out of the body) about thirty or forty feet per second, while in muscles which have been cut out of the body, on account of their reduced vitality, it is only about fifteen feet per second. In plain muscle tissue the rate of such a wave reaches the low minimum of three to four inches per second. Such a wave of contraction in plain muscular tissue may be easily seen in the creeping peristaltic motion of the intestine. The phenomena here described and the times in which they occur apply only to

living muscles. Muscles which have begun to die, or have been fatigued by excessive work, or have been cooled too much, or have been heated to above one hundred and ten degrees, react much more slowly, and finally refuse to act at all.

The Actual Lifting Power of Muscles.

It is the function of muscles to pull and lift, and their maximum capacity to lift is of course a matter of general interest. The amount which a muscle can lift varies with its cross-section in the same way that the capacity of a rope to sustain a weight depends upon the thickness of the rope. With frog's muscle, experiments indicate that a muscle a square centimeter in cross-section can lift about six and one-half pounds. A square centimeter of muscle in man may lift as much as twenty-five pounds under the stimulus of the will. When we remember that some muscles are many square centimeters in cross-section the force with which they may be made to lift and pull is easily explained.

Amount of Shortening of Muscles.

Another question of interest is the proportionate length to which a muscle may contract itself. This, of course, varies somewhat with different muscles. A short, thick muscle would not shorten itself as much as a longer slender muscle. Varied experiments indicate that the actual reduction in length may be from sixty-five to eighty-five per cent. of the entire muscle.

Changes in Volume.

A muscle when it contracts occupies a little less volume than it did in an expanded state. This is no doubt due to the fact that in the contraction, some of the muscle substance is more compressed. This may be easily demonstrated by hanging a muscle in a vessel of water and then making it contract. On the contraction, the height of the water in the vessel sinks a trifle.

Muscle Fatigue.

One of the most familiar phenomena of our muscles is their fatigue resulting from hard work. This fatigue is caused by an accumulation of waste matter in the muscle substance, owing to its active work. This may be easily demonstrated by taking a frog's muscle, and causing it to contract until it is thoroughly fatigued and refuses to react to further stimuli. If now such a muscle be washed with water which contains a little salt, so as to make the water as nearly like blood serum as possible in that respect, it begins to contract again with apparently renewed energy. The only explanation available is that the salt water in question washed out some of the waste products. Of course this could not be continued indefinitely, for soon the muscle fibre not being nourished would be robbed of all its material, and so a final exhaustion ensue. This explains why a muscle fatigued revives so quickly when it is moved about freely, and for a few minutes the blood is allowed to stream into it uninterruptedly. This feeling of fatigue, however, does not come directly from the muscles. The muscle fibres are supplied with motor nerves only, and it is probably impossible to receive a sensory impression from them. There are, however, distributed between the muscle fibres sensory nerves, and from these we derive our muscular sensations. Some of these nerve fibres seem to end in little special end organs which suggest the Pacinian bodies of the mesentery. In fact, some histologists believe that the spindle cells mentioned on a preceding page* as cells which develop later into new muscle fibres, are not muscle cells at all, but are sensory cells connected with nerves, and that from these to a large extent we get our muscular sensations.

The Blood Supply.

The vitality of a muscle is very dependent upon its blood supply. If the artery going to a muscle be cut, or if only venous blood be able to reach it, the muscle at once begins

*See page 119.

to atrophy. There is in the body a nervous arrangement by which the blood-vessels leading to the muscle are at once enlarged as soon as that muscle is called into action. These are the dilator nerves, which will be treated in detail in the chapter on circulation. By this arrangement a working muscle receives an extra amount of nourishment, and of oxygen, to carry on its added work. The vitality of a muscle seems also to be dependent upon its connection with the nervous system. A muscle with its nerve cut begins to atrophy at once. The fibres become shrunken and turbid, and soon lose their power of contractility. This explains why in persons suffering with paralysis the muscles begin so rapidly to shrink and weaken.

Electrical Phenomena in Muscles.

When a muscle is cut out of the body and tested with a galvanometer there may be demonstrated running through its substance small currents of electricity. The central or uncut portion of the muscle seems to be positive with reference to the cut ends. Thus, if the wires be placed one on the center of the muscle and the other at the end, a current runs through the wires from the central portion toward the ends, and of course in the muscle, to complete the circuit, from the ends toward the center. These currents have been

Fig. 68.—DIAGRAM TO SHOW THE DIRECTION OF THE MUSCLE CURRENTS IN AN EXCISED MUSCLE.

e, f, central positive portion; *a, c, b, d*, cut negative ends. The lines with arrows indicate the direction a current would take between the points touched. In lines 6, 7, 8, no current appears for obvious reasons.

called the muscle currents. They have, however, probably no real physiological significance, because it has been found in many different fields that a tissue which is injured and dying becomes electrically negative to tissues left unhurt. As the muscle where it was cut at the ends has begun to die, these ends have become negative with reference to the central unhurt portion. For this reason when connections are made currents circulate. These currents are, consequently, not found in living muscle, because in this latter case there are no dying portions to be negative.

WAVE OF NEGATIVE VARIATION.

If now, such a cut-out muscle be connected with the galvanometer, and the presence of the current circulating through it indicated by the rotation of the magnetic needle, and if while this is going on, the muscle be stimulated to contraction, it is found that during the latent period the needle tends to swing back to its original position. This indicates that during this latent period there must have been set up in the muscle substance currents of electricity which run counter to the first currents, and so neutralize them to some extent, causing the needle to swing back toward its resting point. This current is called the wave of negative variation. This wave is explained on grounds similar to that of the ordinary muscle currents. The muscle substance not only when dying, but also when stimulated, becomes negative at such points. As the nerve enters the muscle near the middle, and as, therefore, the point of stimulation arises here, this becomes negative toward the ends of the fibres which the stimulus has not yet reached. Thus there will be set up counter currents tending to run from the more positive ends to the negative middle. But as these run in exactly the opposite direction to the currents caused by the dying negative ends, they tend to neutralize each other more or less, and so the needle swings back toward the resting point.

This wave of negative variation referred to occurs in living muscle, and its presence there may be indicated by a sensitive galvanometer. The rate of this wave has been measured, and is in the muscles of mammals about three meters per second. The time required for this wave to traverse the entire muscle is only about one three-hundredths of a second. As the latent period is about one one-hundredth of a second, this wave of negative variation is entirely over before the wave of contraction follows.

This wave then has physiological meaning. The deflection of the magnetic needle connected with the muscle indicates that there are going on in this latent period peculiar molecular changes, the nature of which we do not yet at all understand, but which get the muscle ready for the contraction which follows just an instant later. This wave running along a muscle may be actually used to stimulate the nerve of another muscle. If, for instance, two muscles with their nerves intact be removed from a frog, which muscles we will call here A and B, and the nerve of A be laid on the muscle of B, and then the nerve of B stimulated so that B will contract, it is found that not only does B contract, but A contracts also. This is explained in this way: Every time B is stimulated by its nerve a wave of negative variation runs along it, which wave acts as an electrical stimulus to the nerve of A which rests on it, and so the nerve of A, being stimulated, produces a contraction of the muscle of A. If, then, B is tetanized, a corresponding tetanus is produced in A, showing that each single impulse has its own wave of negative variation preceding it.

Rigor Mortis, or Death-Stiffening.

Soon after death, varying from a few minutes to not more than several hours, the muscles of the body become intensely rigid, preventing the bending at the joints, a condition familiar as "death-stiffening," or rigor mortis. This rigor begins as a rule in the muscles of the lower jaw and neck, then seizes the upper extremities and gradually ex-

tends to the lower extremities. After some time this rigor begins to disappear and the dead body again becomes movable at its joints. This loosening is usually attributed to the beginning stage of decomposition, but this is probably not right. According to the more general explanation rigor mortis is due to the clotting of the muscle plasma. Such a formation of a solid muscle clot would of course at once explain the immobility of the body. A more recent view, however, and one which seems to have most in its favor, explains rigor mortis as a final severe contraction of the muscles brought about by the chemical changes which induce death. It would be, in other words, a severe tetanus produced by a series of disintegrating chemical changes which accompany the dissolution of life. According to this view the relaxation which follows after the rigor would be merely a return of these muscles to their relaxed condition. That this rigor is probably a contraction and not a mere coagulation of internal albumens is further supported by the fact that a good deal of heat is liberated, and that the muscles show all those phenomena which accompany ordinary severe contraction.

The Source of Muscular Energy.

The view that muscles possessed a kind of vital energy, which of course could not therefore be measured like ordinary physical energies, has long been abandoned, and we know now that muscles must derive their energy to contract in accordance with the same laws that determine what the energy-yielding power of an ordinary steam engine or dynamo shall be. Muscle energy is identical *per se* with physical and chemical energies. The question now arises, in what manner, from the material that is carried to it by the blood, does it get its energy to produce heat and motion? Without going into a discussion of older views, the following seems the explanation most in accord with all the observed facts.

When a muscle contracts some of its living muscle substance disintegrates into simpler compounds, and by this disintegration energy is set free which the muscle utilizes, much as in the case of a bit of nitroglycerine. The nitroglycerine disintegrates into simpler chemical compounds, and by the disintegration a large amount of energy is liberated to lift the rock, remove the stump, or what not. A muscle contraction is, therefore, in reality a muscular substance explosion differing from the nitroglycerine analogy, in the fact that there are but particles, here and there, throughout its substance which disintegrate, and not the entire muscle itself. The old view that a muscle contracts because at the time of its contraction something is oxidized is not correct. This may be proved by removing from a muscle all traces of oxygen and then stimulating it. It will contract as usual. Muscles must, however, have nourishment and air carried to them to be built up, to have these wastes repaired, but not to produce the direct contraction. As for the same reason there would have to be carried to the nitroglycerine factory all the ingredients to make nitroglycerine without any intention whatever of having the explosion occur by doing so.

Now, muscle substance is mainly albuminous. The question at once arises whether any foods other than albumens may serve to nourish the muscles. That other foods may figure so is argued by the fact that most of our muscular domestic animals are herbivorous; that is, their food consists largely of other than albuminous material. There seems, therefore, a difficulty at first in explaining how foods not albumens, that is, containing no nitrogen, can be built into living muscle substance which is albuminous, that is, which does contain nitrogen. This apparent difficulty is removed, however, at once, by observing that a working muscle seems to retain all the nitrogenous products which have resulted in the muscle disintegration. Or, to be more explicit and to the point, the living muscle albumen disintegrates into products which contain the nitrogen and into

other products free from the nitrogen. The main nitrogen-free product resulting from this muscular explosion is carbon dioxide (CO_2); which is then eliminated through the lungs. The nitrogenous products are, however, retained by the muscle and with nitrogen-free foods, such as fats and sugars, may be re-combined to form new living albumen. This albumen may then disintegrate a second time, the nitrogen-free products such as carbon dioxide may be sent out, while the nitrogenous products are again retained, again to be united with fats and sugars and built into new muscle substance.

Observations made on working muscles are in marked harmony with this view. Thus, every one knows that the harder one works the more carbon dioxide does one breathe out of the lungs; but very careful experiments have shown that the amount of nitrogen eliminated through the kidneys does not all vary with the work done, a man working hard not eliminating any more nitrogen than one idle. If, of course, all these nitrogenous products formed in the disintegration of muscle could be retained and thus used over and over again, somewhat like a brass shell might be re-loaded and so used over and over again in firing, if nothing were lost, there would be no necessity in a full grown man of introducing new albumens into his system. But in these repeated disintegrations, although most of the nitrogenous products are saved and used over and over again, a little incidental loss, a kind of wear and tear incident to all changes results, and it is this little bit which is then sent to the kidneys finally to be eliminated. To replace this wear and tear it is absolutely necessary to put into the blood new nitrogen-containing foods such as albumens. This explains in an unusually clear way how such substances as fats, sugars, and the starches may be gradually utilized in building up muscle substance. It explains further, the impossibility of doing without albumens, that is, nitrogenous foods, altogether. It explains why the carbon dioxide is in a general way doubled in amount when the work is doubled.

It explains, finally, why the working body will eliminate practically no more nitrogen from the kidneys than an idle one. Much in the same way as a machine standing still may have as much rust and wear and tear in its machinery as an engine in proper use.

The reason at last why in a working muscle the arteries are thrown open and the arterial blood carrying the oxygen and the nutritive substance of the plasma streams pell mell through the muscle is, therefore, not to have it contract the more, but to give it the opportunity of repairing its substance as rapidly as it is being disintegrated. The blood stream would be like the soldier carrying the ammunition to the gunners, in order that they might make good with new powder the losses resulting in their rapid firing.

The Mechanics of the Muscles.

THREE CLASSES OF LEVERS.

With the exception of a few muscles which surround cavities, like the muscle around the mouth, all voluntary muscles are inserted into bones, and produce with these various kinds of levers used in supporting or moving the frame. In every lever there are three points: the point about which the lever turns, called the "fulcrum," the point at which the weight is placed, and the point at which the power is applied. According to the way in which these three points are grouped, levers are divided into those of the first class, the second class, and the third class. In a lever of the first class the fulcrum lies between the "power" and the "weight." A familiar illustration of such a lever is found in the ordinary weighing balance, which is a beam suspended in the middle from a fixed point, the fulcrum, while the "weight" and the "power" are applied at the opposite ends. Numerous other illustrations might be adduced. The further illustration of the teetering-board will suffice. There are few levers of this kind in the body. The nodding of the head is one. In this instance the fulcrum is at the point where the occipital bone rests on the

atlas, the power is applied where the muscles of the neck are inserted into the skull, while the final weight of the head might represent the "weight." A second illustration of this lever is found in the act of bowing. In this case the fulcrum is at the hip joint, the "power" is applied where the muscles of the hip are inserted to pull the body backwards, while the forward weight of the body represents the "weight." In such a lever little is gained except a change of direction; a power pulling down may, with such a lever, pull a weight up.

In a lever of the second class the "weight" is between the fulcrum and the "power." The ordinary wheelbarrow is a lever of this class, having its fulcrum at the forward wheel, the "weight" in the bed, and the "power" applied where the hands grasp the handles. A crowbar in prying upwards, as in rolling a barrel, is a further illustration. There are not very many levers of this order in the body. The best illustration of this lever is found in the ankle. When the body is lifted the toes become the fulcrum, the weight of the body rests on the astragalus, while the "power" is applied at the end of the heel where the tendon Achilles of the calf of the leg is applied. It is evident that by means of such a lever a greater weight may be lifted than the power could lift directly, for the experience of everyone will convince him that by means of a wheelbarrow a man may lift a greater load than he could by directly hoisting it with his arms.

A lever of the third class has the "power" between the fulcrum and the weight. Most of the levers of the body are of this kind. The flexing of the forearm at the elbow is an illustration of this class. Here the fulcrum is at the elbow, the weight is in the hand where the object to be lifted is held, and the power where the tendon of the biceps muscle is imbedded in the radius. It is evident that in such a muscle much power is lost, for the muscle, in order to raise a certain weight at the end of the radius, would have to pull much more than that weight by pulling on the radius

near the elbow. Just as it is more difficult to lift a heavy weight on the end of a long fork than it would be to pick it up directly. But while such power is lost, rapidity of motion is gained, but a slight contraction of the biceps muscle causing the hand to move through quite a distance. Such arrangements in our bodies indicate that the levers were intended rather for dexterity and rapidity of motion than for the ability to lift mere weights. However, in the case of the ankle, at which point we have to lift at each step the weight of the entire body, a lever of the second class is put, an arrangement by which a person is never obliged to pull as much on his muscles as the weight of his body actually is.

THE MATHEMATICS OF LEVERS.

In every lever, no matter whether of the first, second or third class, the distance from the power to the fulcrum is called the "power-arm" (pa), while the distance from the "weight" to the fulcrum is called the "weight-arm" (wa). In all three classes of levers the following simple arithmetical proportion holds true: That the $P:W::wa:pa$. Hence, if three of these factors are given, by the simplest mathematical process the fourth may be determined. To illustrate in a specific case: If we assume in the case of the foot the distance from the toes to the astragalus to be seven inches, and the distance from this point in the astragalus to the point where the tendon is attached to the heel bone two inches, we have the power-arm of seven inches plus two inches, or nine inches, and the weight-arm seven inches. If, now, a man's body weighs, say, 160 pounds, which is therefore the weight, how many pounds must his tendon Achilles pull in order to raise him on his toes? By the equation $P \times pa = W \times wa$. Calling the power x gives $9x = 7 \times 160$. $x = 124\frac{4}{9}$ pounds. Thus, by means of this arrangement, to lift a body of 160 pounds requires a pull of only 124 pounds at the heel.

Or, to take a second example in the case of the forearm. Suppose the distance from the elbow to the point in

the hand where the weight rests to be fourteen inches, and the distance of the point where the biceps muscle is attached to the radius, to be three inches from the elbow. With what power would the biceps muscle have to contract to raise fifty pounds in the hands? In this case the power-arm is three inches and the weight-arm fourteen inches. By the terms of the equation $3x = 14 \times 50$ and $x = 233\frac{1}{3}$ pounds. In this case much power is lost, for to lift but the rather small weight of fifty pounds requires a pull of $233\frac{1}{3}$ pounds of the biceps, and this on the supposition that the biceps is pulling in the most advantageous direction, while as a matter of fact pulling at an angle adds a further disadvantage. But while much power is lost in this way, but a slight contraction of the biceps moves the hand through a much greater distance. By means of these various levers all through the body we are enabled to accomplish the familiar movements of walking, running, jumping, swimming, and so on. The exact manner in which these various movements are brought about may be so easily determined by direct observation that a full discussion of them is here omitted.

The Hygiene of Muscles.

There are but two things in the body which are under our immediate control. One of these is the system of voluntary muscles, and the second is the central nervous system. These two systems are placed in our own hands, and for the growth and development of them, we ourselves are directly responsible, and as on the development of these two systems nearly all the other systems depend, we are enabled in an indirect way to be masters of our whole frame. There are, therefore, but two kinds of exercise under our immediate control—muscular exercise and nervous exercise. Two kinds of education—or, rather, two phases of the same education are, therefore, possible, a physical education and the education of the mind. No one questions for a moment that the mind, if left to itself to

shift as it may, if never carefully directed, will ever become properly developed. But we do not yet seem to be so clear in reference to the muscular system. In these days, when intellectuality is frequently made to count so much more than health, the exercise of the body is put in the background, in fact, lost sight of too often. "A sound mind in a sound body" is an old maxim, and its validity is not questioned by thoughtful people. But not only do we want a sound body in order to have a sound mind, we want a sound body for its own sake. It is absolutely indispensable in those trades which demand manual labor and physical exercise, and is a necessity in intellectual pursuits and sedentary occupations. This is evidenced by the number of men engaged in brain work who fall by the wayside while they are yet young. It is illustrated every day in men of especial mental acumen who have their sun set while it is yet day. Exercise is the education of the body, in which sense the term education is identical with that when applied to the mind. Properly directed exercise is the fitting of each part to fill its place fully, and to have it completely adapted to the other parts. Exercise is not the excessive or peculiar development of one side or another, it is the all-round development, the result of which is so tersely expressed in that familiar word "health." In olden times exercise was made the larger part of the training of the young soldier and sailor. Common experience has proved that this was an indispensable preparation for the taxing and arduous endurance of warfare, but they selected the strong, the brave, the courageous, while the weak, the undeveloped, were neglected and pushed to the wall. In too many ways does this ancient notion still crop out with us. How many times in our schools and colleges are not the strong picked out for such training and exercise to appear in competitive games, while the weaker ones who need it most are permitted to sit in silence in the grandstand and watch the sport.

In the physiological use of the term *exercise*, reference is not had to the production of special strength nor the

peculiar training for an especial exertion, but to that rounded training that makes for health. We all know that properly directed exercise strengthens the muscles, vitalizes the body and increases its powers of resistance and of work. To the athlete such a system of rigorous training is recognized by everybody to be indispensable. But not only the soldier on his marches or the athlete in his contests, but the minister, the teacher, the lawyer and the merchant as well will later be called upon to undergo as much fatigue and will have demands made upon their bodily strength no less than the former. The many failures to meet these demands in the sedentary vocations ought to be a warning. The intellectual professions are filled with many men who in spite of their sincerest efforts, in spite of a real enthusiasm in their work, drag themselves through their tasks with languor and pain, weariness and discouragement, and with the imminent possibility of a nervous break-down always hanging over their heads, when by a properly exercised and educated body they might have been enabled to prosecute their work with pleasure and comfort.

What accounts for this seeming neglect of our bodily health? The principal reason is no doubt the fierce competition in the field of nerve and brain. From the nursery to the college or university the nervous strain goes on. Entrance tests, promotions, appointments to scholarships or fellowships, competitive examinations, grades of merit, late hours, weary reading, a slavishness to books, a straining after facts, a crowding and cramming, until finally the man is brought to a halt in his mad career by finding his body weakening under the protracted pressure, and his energies both of mind and frame irreparably injured. In America especially a premium is put upon intellectual precocity. Pale, bookish children are put on the grandstand for exhibition, to be admired by parents and patrons, while the ruddy-faced, broad-shouldered boy whose mind too frequently runs to games and to whom the attractions which field and meadow, and wood and stream afford are prefer-

able to the prosy text-book, is ridiculed and classed as a dullard. But in spite of the praise showered upon the former, it ought to be an object of our pity, while the ruddy health and the out-door instincts of the latter ought to be things to emulate. This does not mean at all that the training of the mind ought to be put into the background, for no less than the muscles the mind needs its proper amount of exercise to grow, but when such mental exercise, especially in children, has reached the point of fatigue, considerations of health call for a halt and invite attention to the bodily wants of the child in question.

Modern life has become such a severe struggle for existence that in the battle all else is lost sight of except the ultimate goal desired, and so persons subject themselves to greater and greater mental pressure in the firm belief that they cannot afford as a matter of time and money to stop in their foolish expenditure and look after the wants of their mere bodily frames. A second reason is possibly found in that element of American civilization characterized by foreigners as our "hurry." We object to walking when it is possible to ride; we object to doing anything with our hands when it may be done more quickly in other ways. To take sufficient time for our meals seems frequently impossible on account of the demands on our time made by our business, while to break into the hurry and routine of the daily work by taking a quiet, restful walk in the open, fresh air an hour in the morning and an hour in the evening seems entirely out of the question. We act on the apparent belief that all of our business is so pressing that we must jump on the quickest car home, eat our dinner in the most hurried way, make the closest connection for a car returning, and return at the end of such a day's work not earlier than supper. The third reason is possibly found in the fact that when one becomes accustomed to doing without exercise there grows upon one more and more a disinclination to take it. In this way exercise becomes more and more a task, is more and more dreaded, avoided, and

the muscles on account of their continued idleness become more and more weakened, until finally healthy bodily exercise becomes not only a hardship, but an impossibility.

No directions can be given with reference to the amount of exercise to be taken. In the case of young children, their love of outdoor games is a natural solution to this question. In the case of adults, especially those who are engaged in sedentary professions, at least two or three hours a day ought to be taken in good, invigorating out-door exercise. If an equipped gymnasium, such as are becoming more and more prevalent, be not available, the best substitute is a brisk walk in the open air. To get the proper amount of exercise for an average individual, the walk of a day ought to amount at least to three or four miles. If, however, the out-door exercise may be changed into some kind of a game which shall bring about a mental relaxation, as well as mere physical exercise, much additional is gained, for the individual who walks along engrossed in his usual train of thoughts loses the most helpful effects of his ramble. There can be no questioning of the fact that the many national out-door games in England have had very much to do in making the English character, and possibly no greater good could befall this nation than to have encouraged in it a more and more general appreciation of out-door sports in which it would be possible for everyone to participate.

CHAPTER VIII.

THE CIRCULATION.

In order that the blood may be of service in the body it is necessary that it be kept in circulation. This for two reasons: It must bring new nourishment and new oxygen to the part in question, otherwise the tissue would soon be exhausted, and it must carry away those products of decomposition resulting from the activity of the tissues, otherwise these products would accumulate to such an extent as to become poisonous and prevent further work. To accomplish these purposes the entire amount of blood is kept in one constant whirl, not stopping even for an instant throughout the entire life of the individual. The stoppage of blood an instant or two would at once entail death. And when it is told that a single particle of blood is whirled along at such a speed that it makes one complete circulation in little more than half a minute, passing in that short interval twice through the heart, through the capillaries of the lung and over the system, one may realize with what energy and rapidity the circulation is going on. The main reason for this speed is found in the necessity for carrying the oxygen to the tissues rather than the nutritive portions of the blood. These nutritive substances soak rather slowly through the tissues in the lymph, while the blood itself, confined in definite vessels, is hurried along at pell-mell speed back to the lungs to carry to the tissues new quantities of oxygen.

In many of the lower animals the necessity for a circulation is not so great. Thus some of the very tiny forms are able to have their nutritive substances soak through all parts of their bodies by the simple process of osmosis, while the air, too, may be taken in sufficient quantities through the

(Facing Page 146. See Page 155 et seq.)

Fig. 74.—THE ARTERIAL AND VENOUS SYSTEMS IN JUXTAPOSITION. (From Quain, after Allen Thomson.)

The explanation of the letters and numbers will be evident from references to the text and to the other figures.

exterior without having special avenues set apart for carrying it. Then on account of the sluggishness of many of the invertebrates, and the further fact that their bodies need not be kept at the relatively high temperature of warm-blooded animals, their need of a rapid circulation does not exist. In such cases, as for instance the clam, the blood circulates in a much slower and less perfect system than in higher forms.

In the insects an entirely different arrangement is found. The activity which many of this class exhibit would make it imperative to have at the disposal of their tissues abundant quantities of oxygen, and if such were to be carried by the blood from some central lung, it would have to run at a speed possibly none slower relatively than that found in us. But oxygen in these little active creatures is not carried by the blood directly, but is carried through special vessels which branch and re-branch, carrying the air from the exterior to every part of the body. In other words, the insects have a system of air arteries and air capillaries permeating the entire body to the minutest parts, and by this system sufficient quantities of oxygen are carried. The blood in this case, being relieved of its main function, circulates in a very imperfect way, and the blood system is not at all well developed.

Simplified conditions are also met in the lower forms of vertebrates. Thus in fishes the heart consists of but one auricle and one ventricle. In the frogs and allied forms there are two auricles, but one ventricle only, while, finally, in the higher forms we have four distinct cavities of the heart. By this means the blood reaches the heart twice in one complete circulation instead of only once, as in the fishes, and is thus with almost double energy forced on in its course.

THE GENERAL ARRANGEMENT OF THE CIRCULATORY SYSTEM.

To have any liquid circulate it is necessary that at one point at least in its course it may be subjected to a proper

power to propel it. In every water-works system there must be at least one central pumping station. The central station in the circulation of the blood is, of course, the heart. From this arise vessels which lead the blood away from it, called arteries. These arteries are of two sets, one carrying the impure blood to the lung, the pulmonary arteries, the other carrying the pure blood over the entire body, the systemic arteries. The arteries divide and sub-divide as they proceed, and finally entering their respective tissues lead into the plexuses, or net-works of tiny capillaries. In these capillaries the walls are thin enough to permit the nourishment held in solution in the plasma to dialize through and soak in among the tissues. The oxygen, too, in the capillaries becomes disassociated from the corpuscles which have carried it to this point, and along with some of the plasma which soaks through it enters the lymph of the tissues. It will be seen, therefore, that in the capillaries the arterial stream, so to speak, divides, the larger portion of it, together with all of the corpuscles, remaining in the capillaries, and, being returned to the heart through the veins, while the other part soaks through the capillary walls and slowly and leisurely circulates between, and permeates, the tissues. This latter part is designated as lymph. Lymph, therefore, is but that portion of the blood which has dialized out through the thin capillary walls.

The returning streams, then, are two. First, the veins which carry the returning blood that has not left the capillaries, and which, because they contain all the red corpuscles, look red, and are therefore spoken of as blood veins; and second, a system of so-called veins, the lymphatics, quite similar to the ordinary blood veins which gather up the lymph of the tissues, and finally through the thoracic duct return this stream to the original blood circulation, where the thoracic duct empties itself into the left subclavian vein.

THE ROUTE OF ONE COMPLETE CIRCULATION.

Starting with a drop of blood say in the right ventricle, it is sent by the contraction of this chamber through the

pulmonary artery issuing from it, to the lungs. Here it suffers changes which will be discussed further on, the results of which are, that the dark venous blood is changed into the light arterial blood, which is then, by means of the pulmonary veins, returned to the left side of the heart. Here it flows into the left auricle, at once proceeds to the left ventricle, and by means of this powerful ventricle it is

Fig. 69.—DIAGRAMMATIC REPRESENTATION OF THE CIRCULATION OF WARM-BLOODED ANIMALS.

o, auricles; *v*, ventricles; *P*, pulmonary capillaries; *C*, systemic capillaries; *a, a*, aorta; *v, c*, vena cava; *a, p, v, p*, pulmonary artery and vein.

forced out through the issuing aorta and sent over the body. Carried by arteries it finally reaches the capillaries of the

tissue in question, and after losing some of its substance into the lymph, it is returned by means of the veins to the right auricle as impure blood, and from the right auricle proceeds to the right ventricle, which was its starting point. It will thus be seen that in one complete circulation the blood passes through the heart twice, and passes through at least two sets of capillaries, those of the lung and the systemic capillaries. It has already been stated that this proceeds with such rapidity that the time required for such a complete circulation is but little more than half a minute.

THE HEART.

1.—*Position.* The energy to keep this entire current moving is furnished by the heart, which is a large, muscular organ situated in the chest extending from about the second to the fifth ribs. While it varies in size under varying circumstances its average size may be roughly indicated by comparing it with the double fists of the person. It is placed diagonally in the chest, with the apex extended

Fig. 70.—DIAGRAM TO SHOW RELATIVE POSITION OF HEART IN THE CHEST.

towards the left side striking the chest wall in front, about between the fifth and sixth ribs, while the base extends

upwards and towards the right. As the beat of the heart may readily be felt where the apex touches the chest, this has given rise to the popular statement that the heart is on the left side. As far as actual material is concerned, probably as much of it lies on the right side as on the left.

2.—*Coverings.* It does not, however, hang loose in the chest, but is supported by a double membrane covering it, called the pericardium. The heart does not really lie inside the pericardium, although at first appearance it seems to do so. It is entirely on the outside of it, and the interior of the pericardium is really the space filled by the pericardial fluid between the two membranes. If an ordinary foot-ball only loosely distended be pressed down over a fist so as to surround the fist, we should have an analogous example. It is evident in this case that the fist is not in the collapsed foot-ball at all. This pericardium is attached to the walls of the chest, and in this manner the rather heavy heart is supported. The pericardium is really but a continuation of the pleura.

3.—*Cavities.* As pointed out in a previous chapter, the muscular tissue of which the heart is composed is of a peculiar kind, called the cardiac muscle. This muscle is thrown into such folds and sheets as to form the four cavities of the heart. Of these, the upper cavities are small, and their walls quite thin. In a cut-out heart they are usually collapsed, and look more like little muscular appendages than large chambers. On account of their flap-like appearance they are called “auricles;” that is, little ears.

The two lower cavities comprise nearly all the substance of the heart, are entirely separate from the upper cavities as seen from the outside, have comparatively very thick walls, the left being much the thicker, and are called “ventricles.” It is the contraction of the ventricles that forces the blood through the arteries.

4.—*Vessels Arising from the Heart.* A number of vessels are connected with the heart, carrying blood to it (the

veins) and from it (the arteries). Into the right auricle open several large veins—the descending vena cava, the ascending vena cava, the azygos vein, and several small

Fig. 71.—VIEW OF HEART AND GREAT VESSELS FROM BEFORE. (Quain.)

3, pulmonary artery cut off; 1, arch of aorta; 2, left ventricle; 4, aorta; 5, right auricle; 6, left auricle; 7, innominate veins joining to form the descending vena cava; 8, ascending vena cava; 9, hepatic veins; + + left coronary artery.

coronary veins. The right ventricle is connected with the large pulmonary artery leading to the lungs. The left auricle has opening into it, usually three or four pulmonary veins, while the left ventricle communicates with the large aorta, which through its many branches carries the blood over the entire system. From the aorta close to the heart, two arteries arise which lead through the substance of the heart itself and nourish it. These are the coronary arteries. A conspicuous branch of these coronary arteries and the corresponding returning coronary veins, may be easily

seen on the exterior along the partition which divides the right and left ventricles.

5.—*The Valves of the Heart.* In order that by means of the contractions the blood may flow in the proper direction, the heart is provided with a series of valves, four in number, two between the auricles and the ventricles, one at the beginning of the pulmonary artery, the fourth at the beginning of the aorta. The valves below the auricles are called auriculo-ventricular valves. The valve between the right and left auricle consists of three flaps so arranged

Fig. 72.—THE HEART WITH RIGHT AURICLE AND RIGHT VENTRICLE EXPOSED.

1, descending vena cava; 2, ascending vena cava; 2', hepatic arteries; 3, 3', 3'', walls of auricle; 4, wall of ventricle; 4', papillary muscle; 5, 5', 5'', tricuspid valves; 6, semilunar valves; 7, pulmonary artery; 8, aorta; 9, branches of aorta; 10, left auricle; 11, left ventricle.

that when they are brought together they close the opening leading to the auricle. This is the tricuspid valve. The

valve between the left auricle and left ventricle consists of but two flaps, and is therefore called the bicuspid, or, from its resemblance to a mitre, the mitral valve. A rather rough illustration of these valves may be made by cutting say the top of an ordinary tomato can in such a way that it will be divided into three triangular flaps, meeting at a point in the middle of the surface, somewhat like a pie cut into equal thirds. If these parts of the can were then bent downward into the can one might easily see how a liquid could be poured into the can. But if these flaps should by the liquid poured in them be gradually lifted up, until finally they should all meet again, and joining with their edges fit perfectly, one may see how the return of such water out through this opening would be prevented. Such is in a general way the condition of things in the heart. To prevent these valves in the heart from turning upwards into the auricles, they are fastened to the walls of the ventricles by means of strong cords called the chordæ tendinæ. Such cords do not end, however, abruptly in the wall of the ventricle. If such were the case, these cords on the contraction of the ventricles would become slack, and so allow the valves to turn back into the auricles. To prevent the production of such slack, the cords run into special muscles attached to the ventricular walls, which by their contraction pull in the slack on the cords as rapidly as it is produced by the approximation of the ventricular walls in the heart beat. These muscles are called the papillary muscles.

At the orifice of the pulmonary artery and of the aorta are the semilunar valves. These consist in each case of three sack-like flaps attached to the wall of the issuing vessel in such a way that when they are distended with blood they meet in the center and prevent the flow of blood past them. These semilunar valves do not differ materially from the valves which occur regularly in veins. These valves permit the blood to push the flaps apart in entering the vessel, but do not permit the flow in the opposite direction. On the middle of the margin of each of these flaps there is

a, occipital bone; *b*, fifth cervical vertebra; *c*, *d*, *e*, first, sixth and twelfth rib respectively; *f*, fifth lumbar vertebra. 1, superior vena cava; 2, 2', right and left subclavian veins; 3, right internal jugular vein; 4, 4', right and left external jugular veins; 5, 5', right and left vertebral veins; 6, left subclavian vein at its junction with the thoracic duct; 7, 7', 8, mammary and intercostal veins; 9, 9, 9, large azygos vein; 10, thoracic duct; 11, inferior vena cava; 12, junction of azygos vein with left renal vein; 13, 13', lumbar veins connected both with azygos vein and vena cava; 14, external iliacs. (A portion of the ascending vena cava, together with the hepatic veins emptying into it, are here shown cut away.)

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Fig. 75.—THE VENA CAVA AND THE PRINCIPAL VENOUS TRUNKS. (From Quain, after Allen Thomson.)

a little cartilaginous nodule called the nodule of Arantius, or corpus Arantii. These may possibly serve to make the edges fit more perfectly. The manner in which these valves

Fig. 73.—THE SEMILUNAR VALVES OF THE AORTA. (Allen Thomson.)

a, b, c, the individual pouches.

act may be easily demonstrated on a beef's heart by opening the ventricles until the semilunar valves in question are exposed, and then pouring water down the pulmonary artery or the aorta toward the heart. In so doing the semilunar pouches as distended, meet in the center, and prevent the progress of the liquid.

THE DISTRIBUTION OF THE VESSELS OVER THE BODY.

1.—*The Arterial Stream.* It is the aorta which springs from the left ventricle of the heart from which all the systemic arteries take their origin. The first arteries branching off, are the two coronary arteries of the heart, which leave the aorta just above the semilunar valves. The aorta then makes a turn to the left, and descends through the chest and abdomen. From the arch of the aorta several important arteries arise. The first is the innominate artery which at once divides into the subclavian, which goes to the arm, and into the right common carotid, which goes to the head. From the right subclavian springs the intra-vertebral artery which goes to the head, passing through the intra-vertebral foramina of the cervical vertebræ. The common carotid divides into an external carotid and an internal carotid, the former going to the face and scalp, the inner to the brain. A little to the right of the origin of the innominate artery the left common carotid leaves the arch of the aorta. In its branching and destination it is the same

as the right common carotid. Further to the left on the arch of the aorta the left subclavian artery arises, going to the arm. From it, too, arises a left intra-vertebral artery taking a similar course on the left side as the corresponding one on the right. The subclavian arteries are in each arm continued as the brachial arteries, and at the elbow divide into two arteries called the radial and the ulnar arteries. It is the right radial artery at the wrist on which the nature of the pulse is usually determined by the physician. These two arteries then divide and in the hand form the anastomosing branches which finally lead into the ultimate capillaries.

Just below the arch of the aorta, but still in the chest, numerous small arteries take their origin, which supply the intercostal muscles. These are called the intercostal arteries. Lying a little anterior to these in each case are small arteries going to the lungs, called the bronchial arteries. These must not be confounded with the pulmonary arteries which carry the blood to the lungs. The bronchial arteries carry arterial blood, intended for the nourishment of the lung, and not sent to that place to be purified.

At the point where the aorta pierces the diaphragm it gives off the artery for that organ called the phrenic artery. Immediately below the diaphragm a number of important arteries leave the aorta frequently so close together as to take a common origin. This common origin or common trunk is, when present, called the *cœliac axis*. Frequently, however, these arteries arise, although close together, still separately. These arteries are the hepatic artery, going to the liver, the splenic artery to the spleen, the gastric artery to the stomach, and the pancreatic artery to the pancreas. A little further down on the aorta the superior mesentery artery carries arterial blood to the small intestines. Then follow the two large renal arteries, then the spermatic arteries going to organs in the pelvis, then the somewhat larger inferior mesenteric artery supplying the large intestine, and finally a few lumbar arteries supplying the body wall. At this point the abdominal aorta divides into a right and left

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Fig. 76.—THE CIRCULATION AT THE BASE OF THE BRAIN, THE CIRCLE OF WILLIS. (From Quain, after Allen Thomson.)

1, left internal carotid artery; 2, left anterior cerebral artery; X, the anterior communicating artery; 3, left middle cerebral artery, passing into fissure of Sylvius, and seen here running over the island of Reil, by the cutting away of the left temporal lobe; 4, left posterior communicating artery; 5, basilar artery; 6, left posterior cerebral artery; 7, 8, 9, cerebellar and vertebral arteries.

common iliac. This in each case divides into an external iliac and an internal iliac. The internal iliac supplies blood to the organs of the pelvis, while the external iliac leaves the trunk and descends through the thigh as the femoral artery. At the knee it is called the popliteal artery, which then divides into the anterior and posterior tibial artery.

The arterial supply of the brain deserves special attention. At the base of the brain surrounding the optic tracks and the pituitary body there is a circular blood vessel into which all the arteries that supply the brain empty. These supplying arteries are the two internal carotids and the two intra-vertebral arteries. The two intra-vertebral arteries, however, unite when they reach the medulla and form the basilar artery which runs from the middle of the medulla to reach the circular blood vessel. This circular blood vessel is called the Circle of Willis. From it in turn arise the numerous arteries which finally supply the brain. By this rather remarkable arrangement several things are accomplished. Every part of the brain may receive blood brought to it in as many as four different channels. Further, the amount of the blood supply of the brain will be constant throughout its entire substance; and lastly, the pulse of the carotid and intra-vertebral arteries is materially reduced in the Circle of Willis, and so the blood reaches the brain largely relieved of these rhythmic pulsations.

THE VENOUS SYSTEM.

The blood returns from the head and neck on each side in three vessels called the external and internal jugular veins, and the vertebral vein. From the arm the blood is returned through the subclavian vein. The subclavian veins on each side have emptying into them the external jugular, then the vertebral, and then join with the large internal jugulars to form the innominate veins. There are thus two innominate veins, although only one innominate artery. The two innominate veins, after receiving several small

veins, unite to form the descending vena cava. Into the descending vena cava there opens usually right close to the heart the large azygos vein, which brings the blood from the back body wall to the heart. Into the right auricle itself open several coronary veins. The blood is returned from the limbs through the external saphenous vein and the internal crural vein. These unite on entering the pelvic region into the external iliac vein, which then joins with the internal iliac vein, returning the blood from the pelvic region to form the right or left common iliac vein as the case may be, which then unite and form the ascending vena cava. Into the ascending vena cava the large renal veins pour the blood which has just been through the kidneys, while close to the heart several hepatic veins enter it, bringing the blood which has just passed through the liver. In the lumbar region branches connect the ascending vena cava with the azygos vein, thus enabling blood from that region to reach the heart by either of two channels.

THE PULMONARY CIRCULATION.

The circulation of the blood through the lungs for purposes of purification is designated by a special name, and is called the pulmonary circulation. This consists of a pulmonary artery springing from the right ventricle and leading to the two lungs, and the pulmonary veins, from three to five in number, which bring the blood back to the left auricle after its oxygenation in the capillaries of the lung.

THE PORTAL CIRCULATION.

In enumerating the veins which empty into the ascending vena cava, one is at first surprised that there are no veins from the stomach, spleen, pancreas, or intestines. The blood, however, which has been carried to these organs is gathered up in a special vein called the portal vein, which is, therefore, of course, made by the conjunction of the gastric vein, the splenic vein, the pancreatic vein and the intestinal veins. This portal vein carries all

(Facing Page 158.)

Fig. 77.—THE ABDOMINAL AORTA AND ITS PRINCIPAL BRANCHES. (From Quain, after Allen Thomson.)

a, hyoid bone; b, pneumogastric nerves; c, c, c, trachea and bronchial tubes; d, œsophagus; e, e, lacteals and thoracic duct; f, f, azygos vein; g, kidneys; g', suprarenal body; h, lumbar vertebra. I, I', I'', thoracic aorta; II, abdominal aorta; 1, coronary arteries; 2, innominate; 3, left common carotid; 4, left subclavian; 5, (on bronchial tubes) bronchial arteries; 6, (on thoracic aorta) œsophageal arteries; 7, (in thorax) intercostal arteries; 8, (on abdominal aorta) phrenic artery; 9, coeliac axis with gastric, splenic and hepatic arteries cut short; 10, superior mesenteric artery; at same level the large renal arteries; below 10 the spermatic arteries; 11, lumbar arteries; below II the inferior mesenteric artery. For explanation of figures in region of neck see the text.

this blood to the liver, where it passes through the capillaries of that organ before reaching the hepatic veins and so returns to the heart.

It will be observed that the blood passing this way passes in one complete circulation through three sets of capillaries instead of two. This circulation of blood through the stomach, spleen, pancreas, intestine and liver is called the portal circulation. The physiological reasons why the blood from the spleen, stomach, and intestines should first be sent to the liver before being returned to the heart, will be discussed in detail in the chapter on nutrition. In anticipation it may be said here that some of the deepest physiological reasons exist for such a course.

THE HISTOLOGY OF ARTERIES, VEINS AND CAPILLARIES.

Examining with the microscope, an artery is seen to consist of three coats, called the inner, the middle and the outer coat. The inner coat consists of a delicate membrane of closely packed elastic tissue, on the outside of which there is a still more delicate serous membrane of flattened cells bound to the elastic membrane by a finely fibrillated connective tissue. The middle coat consists of alternating layers of plain muscular tissue, which is usually arranged circularly, and layers of yellow elastic fibers running mainly longitudinally. The outer coat is the toughest, and is made up mainly of closely felted bundles of white fibrous

Fig. 78.—CROSS-SECTION OF PORTION OF THE WALL OF HUMAN TIBIAL ARTERY. (E. A. S.)

a, inner epithelial coat; *b*, the elastic fenestrated membrane; *c*, muscular layer; *d*, outer coat of connective tissue fibres mainly.

tissue. This coat then gradually shades off into the looser connective tissue in which the artery is packed. These

coats give to the arteries much strength and elasticity, while the development of the muscular coat makes contraction and dilatation possible.

In veins the inner and middle coat are much reduced, but the outer coat of strong, white fibrous tissue is present. For this reason veins have much thinner walls and easily collapse when empty, and, of course, have practically no power of muscular contraction and dilatation. However, owing to the strength of the outer coat, they are, nevertheless, not easily torn. With the exception of the larger veins near the heart, veins have valves in their course. These valves are semilunar folds fastened in such a way as to allow the flow of blood towards the heart, but preventing it in the

Fig. 79.—VALVES IN VEINS.

a, laid open to show pockets; *b*, inner view with valves closed; *c*, as seen from outside.

opposite direction. These valves may occur singly, but are more often in pairs, while in some instances three occur at the same point. By compressing the veins near the wrist the positions of the valves in the congested portions may be recognized by the swollen points along the veins.

Capillaries have all these coats absent, except only the innermost membrane of flattened epithelial cells. This extreme thinness of wall, it being only one cell thick, permits readily the phenomena of osmosis and the migration of the white blood corpuscles.

The boundary lines between arteries and capillaries on the one hand, and capillaries and veins on the other, are

not sharp by any means. The arteries as they grow smaller and branch more and more, gradually lose the thickness of their walls, until finally without a single sudden break in

Fig. 80.—CAPILLARIES AS SEEN IN THE WEB OF A FROG'S FOOT.

the transition, but the inner coat remains, when it is somewhat arbitrarily called a capillary. On the other side, the capillaries have added to them little by little extra elements in their walls, and shade off without a sudden transition here into the veins. By the term capillary, therefore, is included that small portion where all the coats save the innermost are absent, and is more a physiological unit than an anatomical one.

THE PHENOMENA OF THE HEART'S BEAT.

Everybody is familiar with the fact that throughout life the activity of the heart is shown in what is familiarly called the "heart's beat." This beat may be easily recognized in any of three ways: First, where the apex of the heart touches the chest wall on the front and left side there may be felt at each beat a little push or jar, caused by the pressing of the heart against this portion of the chest. The point at which this is most pronounced is between the fifth and sixth ribs. Second, it may be felt in the pulse where the beat of the heart appears as a wave running along the larger arteries of the body. As this is usually more convenient for observation the phenomena of the heart's beat are usually studied in these pulsations. Third, the beat of the heart may be easily detected by the sounds which occur

whenever the heart beats. From the fact that the activity of the heart was so evident, and the further fact that the final evidence of death was usually considered to be the stopping of the heart, the heart received an undue importance, traces of which still remain with us to this day in many words derived from the word "heart," which we use to express courage, emotions, vitality, inner-life, and so on. The finest qualities of persons we sometimes still designate as the "heart" of the man, when, of course, from a scientific standpoint the heart has long been shown to be nothing more than a big muscular pump.

1.—*The rate of beat.* The most easily determined thing about the heart beat is its rate. This is in middle adult life about seventy-two per minute. It is much higher in the foetus, which just before birth reaches 140. From this it gradually sinks through childhood until about the twenty-first year, when the average rate of seventy-two is reached. The rate is a few beats slower in men than in women. Large persons usually have a slightly lower rate than small persons. The actual rate, however, in anybody is subject to great variation. These variations may be owing to temperature, muscular exercise, strong emotions, or be consequences of fevers or administered drugs.

2.—*The events occurring in a single heart beat.* Although the time occurring between two successive heart beats is normally less than a second, by means of proper apparatus the individual events which occur in a heart beat may be easily demonstrated. Let us imagine the condition of the heart at the very instant after a beat is over. Let us suppose that auricles and ventricles are empty, and the muscular substance of the heart is thoroughly relaxed. In this condition the blood is entering the auricles, and as the auriculo-ventricular valves are open the blood at once falls through them into the ventricles. The continued influx of the blood through the auricles, gradually fills the ventricles and floats up the auriculo-ventricular valves. Soon the point is reached

when the ventricles are passively full, and the blood now begins to back up in the auricles. Dividing the time of a complete heart beat into ten periods, the time occupied in this passive filling of the heart occupies six-tenths of the complete time.

At this juncture the auricles begin to contract and force their added amount of blood into the ventricles, which, being already practically filled with blood, now become gorged and distended. By this means the auriculo-ventricular valves become tightly closed. The time required for the contraction of the auricles is about one-tenth of the time. It is not necessary to state here that the two auricles contract together, and the two ventricles together, as if they were in each case but a single structure.

The reason why the auriculo-ventricular valves are closed by the forcing of this extra blood into the ventricles, may be explained by comparing the ventricles to a crowded room. It is easily possible to imagine a room so crowded as to make it impossible to open the door, especially if the crowding should be behind the door. As soon as the auricles have finished their contraction the ventricles begin to contract with much greater force. Just at the beginning of this contraction, when the muscles of the ventricles are becoming taut and tense, the first sound of the heart is heard. Just how it is produced will be explained further on. By the continued contraction of the ventricles the blood is pressed harder and harder, until finally the pressure is sufficient to open the semilunar valves, and the blood flows into the outgoing vessel. The time required by the ventricles in their contraction is about three-tenths of the total period. As soon as the blood has been pressed into the vessels the muscular fibres of the heart relax. The blood in the pulmonary artery and aorta, being under considerable pressure, tends to flow back into the relaxed heart, but in so doing it distends the semilunar valves and closes them. This is the moment when the second sound of the heart occurs. This sound is therefore easily explained. It

is but the sound caused by the "slamming shut" of the doors which lead from the pulmonary artery and aorta back into the heart.

It will be noticed that the heart in its beat is at rest during a greater period than it is at work. The auricles work but one part in ten, the ventricles but three parts in ten, while the entire heart counted as a unit would work but four parts, and be at complete rest, that is, passively relaxed, during six parts of the time. If the chest wall had been removed and the heart exposed, changes in its form might easily have been observed. During the contraction the base of the heart would have changed somewhat from an oval form to a rounded form, while the apex would have been drawn toward the base and become blunter. A material change in the position of the heart does not occur.

Such is, in a general way, the series of events in one beat. Let us now turn to the individual events in detail.

The Filling of the Heart.

Each heart beat consists of two periods: A period of contraction, which is called the systole, and a period of relaxation called the diastole. Thus we have an auricular systole of one-tenth and a diastole of nine-tenths of a beat period, and a ventricular systole of three-tenths and a ventricular diastole of seven-tenths. The filling of the heart falls, of course, in the diastole.

The question naturally arises, as the heart is in a perfectly relaxed and passive condition, what are the agencies that propel the blood forward and cause it to fill the emptied chambers? It was formerly supposed that the pressure of the arterial blood behind the venous blood propelled this backward to the heart. But such a view can easily be shown to be erroneous, for when a vein near to the heart is opened there is no pressure of blood inside it, but there may be actually a tendency to a vacuum, and air be very easily sucked in. This proves beyond question that venous blood is sucked toward the heart and not pushed. No doubt the

mere elasticity of the muscular walls gives a slight suction, much as a sponge unnaturally compressed would as soon as the pressure was relieved, spring to its more natural dimensions. The suction due to this elastic expansion of the walls is, however, a very small factor, and the main power of suction is derived from the aspiration of the thorax itself. As everyone knows the pressure in the thorax is less than on the outside, and a wound through the chest wall would at once suck air into the chest.

In the inspiration the suction action becomes perfectly evident, and a big stream of air rushes through nostrils and mouth into the thorax. If the individual so breathing were in a medium of water, the water would be sucked into the chest with the same relative ease as air. But not only does the windpipe lead into the chest, but the veins do also. Consequently, when the chest enlarges there is a sucking action not only upon the outside air but also upon the outside blood, and the air through the trachea and blood through the veins are sucked heartwards. In very forced expiration the condition of things may be reversed and the veins instead of being sucked may be compressed. But even in this compression the blood is pushed on towards the heart as the valves in the veins interfere with its backward flow. Thus, whether the veins are sucked or compressed, the result is much the same.

That the sucking action of the chest has much to do with drawing the blood into the heart is made evident in the filling of the big veins and the stagnation of the venous stream which occurs when we hold our breath for some time. A person unable to get his breath becomes, as we say, black and blue in the face. He does so because he is no longer able to suck the venous blood issuing from the veins of his skin into the empty heart. As, however, the heart even when the chest wall is cut open, still has venous blood flowing into it in slight quantities, it shows that a small amount of the sucking action must be due to the elastic expansion of the heart itself. It is interesting

to note in this connection that the heart in many of the lower animals is forcibly expanded as well as contracted. In the case of the cray-fish and lobster, for instance, large muscular cords run from the edges of the heart to the body wall, and by their contraction the heart is forcibly distended.

During this filling of the heart, as has been stated before, the blood does not accumulate in the auricle, but runs unhindered into the ventricle until both ventricle and auricle are passively filled. At this point the systole of the auricle begins. The auricle does not completely empty itself, the contraction probably going no farther than the reduction of the dimensions of the auricle to about that of the vena cava.

The Auricular Contraction.

The auricular contraction begins at the mouth of the veins and runs like a wave toward the ventricles. This explains why the blood is not forced back into the veins rather than into the already filled ventricle. As has been stated, this time occupies about one-tenth of a heart-beat period. While the auricular contraction lasts, the on-rushing blood of the veins is of course checked for an instant. This slight checking of the venous stream caused by the inability of the stream to drop into the auricle during the systole of that structure, causes a slight pulsation along the veins known as the *venous pulse*. This venous pulse is not at all so well marked as the arterial pulse, and is due to an entirely different thing. It starts, however, from the mouth of the large veins at the auricle and runs along the veins much like an arterial pulse along arteries. By the contraction of the auricles the already filled ventricle is forcibly distended and so enabled to throw more blood out on its systole. Further, by the pressing of the blood into the ventricles the auriculo-ventricular valves have, in a way already described, been closed. At this point, of course, the systole of the ventricles begins. During this period the auricles act as reservoirs for the entering venous blood and in this role they probably perform their

most important function. Except for this reservoir in which the venous blood may temporarily accumulate there would have been quite a marked stagnation interfering materially with the progress of the venous stream, but by this means the blood flows on into the heart uninterruptedly while the ventricles are beating, and by the time the auricles are filled the ventricles have finished their beat, they relax and the accumulated blood of the auricles drops at once into the emptied ventricles.

The Contraction of the Ventricles.—Sounds of the Heart.

At the beginning and again at the close of the ventricular systole the familiar sounds of the heart occur. The first sound is somewhat dull and represented by the syllable "lubb." It was at first supposed to be due to the closing of the auriculo-ventricular valves, but this is not true. These valves are closed before the systole begins, and in experiments these valves have actually been pinned back, and yet the sound occurred. Still better evidence that the first sound is not due to the closing of these valves lies in the fact that when an emptied heart is made to contract the sound still occurs. While not fully understood, there seems no doubt but that this sound is partially due to the sudden tension of the muscular walls of the ventricles. The ventricular walls becoming suddenly very much stretched and taut, produce a series of vibrations which we recognize as sound. A not very close analogy may be cited in the case of an ordinary guitar string. If such a string at first hanging loosely be suddenly as with a jerk tightened, it will be set into vibration and sound just as if it had been pulled by the fingers. That this sound is due to the tension of the muscles seems corroborated by the fact that the sound lasts during the entire systole. That is, it continues as long as the ventricular walls are taut.

Towards the close of the systole is heard the second sound. This is shorter and louder, and is plainest in the regions of the aorta and pulmonary artery. It has been

represented by the syllable "dupp." This sound is due to the sudden closing of the two semilunar valves. Ordinarily the semilunar valves of the aorta and pulmonary artery close so nearly at the same time that the sound is heard as one. After violent exercise, however, when the pressure in the aorta is materially increased, the semilunar valves at its origin close perceptibly sooner than those of the pulmonary artery, and there are two distinct second sounds. The earlier closing of the valves in the aorta is due to the greater pressure or blood forcing them together, just as two doors entirely alike would close at different moments if winds of different strengths should strike them.

Cardiograms.

All these observations on the events of a heart beat may be best studied by means of cardiograms. These cardio-

Fig. 81.—CARDIOGRAMS OF THE RIGHT AURICLE (RV) AND THE RIGHT VENTRICLE (RK) OF A HORSE. THE DOTTED LINES CONNECT SAME INSTANTS OF TIME.

grams are tracings made by placing systems of levers on the ventricle and auricle, so arranged that the systole of these will raise the levers and the diastole lower them. If, now, the ends of such moving levers be made to trace a line on a plate moving past them at a known speed, there will result curves such as those pictured in figures 81 and 82. The cardiogram in figure 82 is one made on a pathologically exposed human heart, and so is peculiarly valuable as giving the actual course of events in man himself. In this

and in the other figure the upper curve of the cardiogram represents the events in the auricle, the lower those in the

Fig. 82.—CARDIOGRAMS OF THE RIGHT AURICLE (*o d*) AND RIGHT VENTRICLE (*v d*) TAKEN ON AN EXPOSED HUMAN HEART. (After Franck.)

Vertical lines indicate same instants of time.

ventricle. The two are so arranged that vertical lines connect the same instants of time.

The cardiogram of the horse in figure 81 was obtained by pushing a tube provided with a rubber bulb at its end through the jugular vein in the neck into the right auricle, and a second such tube through the auricle into the ventricle. The relative compressions of the bulbs in the diastole and systole were then recorded with a tambour and the curves obtained. Such a tambour consists essentially of a light metallic box, covered on one side with a thin piece of

Fig. 83.—A TAMBOUR.

T, the metal box; *H*, the recording lever resting on the rubber membrane.

stretched rubber. On this rubber rests the recording lever. The metallic box is connected with a tube from the heart,

and the slightest variations in pressure cause the rubber, and consequently the recording lever resting on it, to move up or down as the pressure is positive or negative. The recording lever is then made to write on a suitable surface which is moved along it. Rough cardiograms may be made by connecting two tambour boxes with a rather inelastic tubing, then firmly pressing one over the point in the chest where the cardiac impulse is most perceptible, and arranging the other tambour for the usual way of recording. The pulsations of the chest wall caused by the heart beat will be transmitted through the system of tambours and be recorded on the moving surface. It may not be out of place in this connection to call attention to the fact that this cardiac impulse is not caused by the chest wall being tapped or struck by the heart. The heart never leaves the chest wall, but the impulse is caused by the sudden tension produced at this point when the systole occurs. Much as a person might produce an impulse on a sensitive surface by first laying his hand gently on the surface and then suddenly pulling it up into a fist without removing it from the surface.

On account of the thick wall which separates the tambour from the heart these cardiograms do not give the finer

Fig. 84.—THE POINTS IN THE CARDIOGRAM OF THE VENTRICLE AT WHICH DIFFERENT PHYSIOLOGISTS PLACE THE OCCURRENCE OF THE SECOND SOUND.

detail and are not altogether trustworthy. In their finer determination there are still a number of points not yet perfectly established. Thus, observers have not been able to

agree at what point in the ventricular systole the second sound occurs. In figure 84 are given the views of several of the leading physiologists. It is also an unsettled question whether the ventricles completely empty themselves, or force out only a certain proportion of the contained blood. Evidence seems to point, however, to the fact that the ventricles are practically emptied at each systole.

Pathological Sounds of the Heart.

In a normal heart the auriculo-ventricular valves are hermetically closed and permit no blood to flow back. Sometimes, however, these valves become deranged in some way and cease to close perfectly, thus allowing at each contraction of the ventricle a slight regurgitation of blood into the auricle. The escape of this blood through the imperfect valves gives a murmuring sound easily detected by the physician by means of a stethoscope, and always an evidence that there is a valvular insufficiency.

THE AMOUNT OF BLOOD FORCED OUT FROM THE HEART.

It has been difficult to determine exactly the amount of blood forced out from each ventricle at each beat. (It is, of course, unnecessary to point out that the average amount must be the same for both ventricles.) The amount of blood which is found in the ventricles of a corpse is not perfectly reliable, as post mortem changes may have affected the size of the heart. The first experiments to determine this point gave 175 to 180 grams as the amount sent out by each ventricle at each systole. Later experiments gave 100 grams, while more recently the amount has been put down as low as fifty grams. Taking 100 grams as probably not far from the truth, it would mean that in one minute (seventy-two beats) 7,200 grams pass through each ventricle, or in one hour 432,000 grams. This is approximately 900 pounds, or, expressed in fluid measure, about 112 gallons. In other words, not far from three barrels. And as the other ventricle handles a similar amount, it

means that in the short period of one hour, an amount of blood not far from six barrels traverses the heart.

THE ENERGY WITH WHICH THE HEART WORKS.

In determining the actual work done by anything it is not sufficient to know the amount of matter handled, but we must also know the distance through which it is lifted. Thus, in pumping liquids, it requires just twice as much work to pump the same amount of liquid twice as high. The energy with which the ventricles force out their contained blood is not difficult to calculate. Repeatedly verified experiments show that the left ventricle sends its blood out with such force, that if there were no friction it would be thrown vertically upwards about a distance of nine feet. The force with which the right ventricle throws out the same amount of blood is one-third as much, being in this case a distance of only three feet. Or, to explain this still further, it means that the left ventricle forces the blood out with an energy that would cause the blood to rise nine feet high in a tube, barring friction. Or, to re-state it again, it means that if there were no friction in the arteries the heart would force blood, say, up to the finger tips if the arms should be held vertically upwards, even though the distance from the finger tips to the heart were nine feet.

Now, work is the product of the amount of matter lifted, and the distance through which it is lifted. A unit of work is a foot-pound. A foot-pound is the amount of work required to lift one pound one foot high. Knowing the amount of blood which each ventricle throws out and the height to which it would be thrown if unhindered, it is easy to determine the amount of work the heart is enabled to do in definite periods of time. Thus, at every beat the left ventricle throws out 100 grams, or about $3\frac{5}{16}$ ounces, or about .22 pound, taking approximate figures only. The amount of work is expressed by the product of the numbers giving the amount and height. Thus the work of the left ventricle for one beat would be $9 \times .22$; that is, 1.98 foot-

pounds. For convenience sake let us say two foot-pounds. In seventy-two beats (one minute) the amount of work would be 144 foot-pounds. In an hour, 8,640 foot-pounds.

As the right ventricle lifts the blood only one-third as far, the amount of work it does is just one-third that of the left ventricle. Adding this one-third to the amount of work the left ventricle does in an hour makes 11,520 foot-pounds. Re-stating that again, it means that in one hour the heart has expended an amount of energy that would have lifted 11,520 pounds one foot high.

In the case of a man weighing 160 pounds, it would lift him in one hour to a distance of 72 feet, or in one day 1,728 feet. Even if the strong muscles of the skeleton should be asked daily to carry the body up a mountain side to a distance of 1,728 feet, it would by no means prove an easy task. Yet such is the amount of work the heart does day in, day out, without showing signs of fatigue. To state this in still another way—if the heart weighing 300 grams should expend all its energy in lifting itself only, it would raise itself in one hour to a distance of 13,000 feet. In ability to do work, the heart is equal to $\frac{1}{200}$ of a horsepower.

THE INNERVATION OF THE HEART.

1.—*The Source of the Stimuli.* So far the question has been ignored, what causes the heart to contract? Does it beat in obedience to stimuli which reach it from the outside, like the right arm in obedience to impulses from the brain, or does it beat by stimuli that originate within itself? This general question can be easily answered definitely by observing that a frog's heart cut out of the body will continue under proper circumstances to beat for days, and the heart of a warm-blooded animal will beat as long as it is properly supplied with nourishment and oxygen. This settles conclusively that the impulses to beat do not reach the heart from the outside, but are intrinsic. The question then arises whether these intrinsic stimuli are produced by nerve centers within the heart or by the heart muscle itself.

There is, of course, considerable difficulty in making extended observations on the heart of mammals, but it is quite easy to make such observations on cold-blooded forms, especially on the frog and terrapin. If, now, a frog's heart be carefully examined for nerves, two clumps of ganglia may be found, one clump lying near the opening of the large veins, in the so-called sinus. These ganglia are called after their discoverer, the ganglia of Remak. The second clump of ganglia lies in the septum of the auricles close to the auriculo-ventricular valves. These ganglia are called the ganglia of Bidders. The apex of the ventricle is entirely free from nerve cells. As has been stated, such a heart properly treated will continue beating for days with its regular rhythm. If, now, the portion containing the ganglia of Remak be cut away from the rest of the heart, the heart stops beating at once, while the sinus which still contains the ganglia of Remak continues its beat without interruption. This observation was first made by Stannius, and is still spoken of as the experiment of Stannius.

It would seem that the only way to explain this would be to assume that the ganglia of Remak are automatic ganglia which produce the beating, and that the other ganglia are stimulated reflexly by these. For if a heart so severed from the ganglia of Remak be stimulated in some mechanical way it will beat for a while more or less irregularly, but soon comes again to a standstill. This experiment then would seem to be a clear assurance that the beat of the heart is inaugurated by the ganglia of Remak, and is therefore of a purely nervous origin. The function of the ganglia of Bidders could be explained by supposing that they were stimulated by the ganglia of Remak, and so the contraction carried into the ventricles. But there are many facts which will not admit of such a simple solution to the problem. If, for instance, the apex of the heart, which of course contains no nerve cells, be cut off from the rest of the heart it may be made to beat regularly. Here, of course, is a clear case that the beat is not due to nervous influence.

Physiologists have, therefore, been driven to the belief that the heart muscle itself has a kind of automaticity which helps to produce the rhythmic beat.

That these muscle cells themselves must be to some extent automatic may be further conclusively shown by cutting out a strip of muscle from a terrapin's heart, which has no ganglia in it, and observing that such a strip will continue to beat rhythmically if it is once started to do so. Nervous influence is here again entirely out of the question. There are still other reasons to think that heart muscle is automatic and determines its own rhythm. Thus, the heart muscle cannot be thrown into a tetanic contraction, no matter how rapid the stimuli. If the heart contracts at all it will beat with its own rhythm. Then again, the contraction of the heart does not vary with the strength of the stimulus. A slight stimulus will not produce a slight contraction, and a stronger stimulus a stronger contraction, as in the case of all other muscles; but if the stimulus acts at all, be it strong or weak, it will produce the natural rhythmic beat.

What has been said so far with reference to the innervation of the heart has been observed on the lower animals, but there is every reason to believe that practically the same conditions exist in the higher animals. By way of summary be it stated what the condition of things probably is in the *human* heart. Near the mouths of the veins entering the auricles are groups of ganglia called here, also, the ganglia of Remák. A second group of ganglia occurs in the septum between the auricles at the place where this touches the ventricles; that is, in the walls between the two auriculo-ventricular valves. But unlike the frog, scattered ganglia are found through the apex of the heart. As in the case of all animals where observations have been made, the impulse to beat in the human heart is intrinsic and is due probably to two things. First, the ganglia themselves in the heart are probably automatic. Second, the heart muscles as well possess an automaticity, and the beat is the result of these two similarly directed influences.

The word "automatic" has been used a number of times, and a definition of the meaning of this term is imperative in order to understand what is meant by saying that both the ganglia of the heart as well as the muscle itself are automatic. Such a definition of this term is unfortunately not yet forthcoming. Physiologists are so far entirely unable to explain what it is that causes the ganglia to originate their nervous impulses, or the muscle to contract at definite periods. There is probably something either in the structure of the heart or the manner in which it works that excites the ganglia or the muscle substance, but so far it has been impossible to locate that. Thus the term automatic is used to designate a physiological condition of things, the meaning of which we do not yet have.

2.—*Nerves reaching the heart from the outside.* In addition to the intrinsic nerves of the heart three kinds of nerves reach it from the outside. Two of these nerves reach the heart from the vagus or pneumogastric nerve coming from the brain. The third kind reaches it from the sympathetic system.

The fibres of the pneumogastric which run to the heart are really not fibres of the pneumogastric at all; they are fibres of the eleventh pair of cranial nerves called the spinal accessory. A branch of the spinal accessory nerve unites itself with the pneumogastric and follows the course of the pneumogastric through the skull and the neck. If this cardiac branch of the pneumogastric be examined histologically it is found to consist of two sets of fibres, a set of small fibres and a set of larger ones. Both, however, are medullated. On reaching the heart the large fibres can be traced into the heart, leading probably to the intrinsic ganglia, while the set of small fibres seems to run along the surface of the heart and loses itself in the walls of the ventricles mainly. These smaller nerves are sensory and carry to the brain the sensations of the heart.

The Pneumogastric or Cardio-inhibitory Nerves.

The larger nerves, ending probably in the intrinsic ganglia themselves, exercise a peculiar and interesting control over the beat of the heart. When they are stimulated they cause the beat to be slowed, and if sufficiently stimulated may cause the heart to stop beating altogether. For this reason they are called inhibitory nerves. When these inhibitory nerves by sufficient stimulation cause the heart to stand still the heart stands still in diastole, perfectly relaxed, and not contracted in a systole. These cardio-inhibitory nerves not only slow the rate of the beat, but they make the individual beats weaker. The result of this action is, of course, to reduce the blood pressure in the arteries, because the heart no longer forces the blood into these arteries at the accustomed rate. These nerves seem to be acting all the time in our bodies and thus continually keeping the rate of the heart beat in check. For when both nerves are cut the heart at once begins to beat faster, because the inhibitory action of the vagi has been removed.

Inhibitory Center.

It is, of course, not these nerves themselves that are inhibitory, for nerves are but the avenues of impulses transmitted to them. These inhibitory impulses originate in a center which lies in the medulla, called the cardio-inhibitory center. From this center the inhibitory fibres of the vagi run to the heart, and it is of course this center which is in a continual state of excitation and so continually exercising a checking control of the heart.

This cardio-inhibitory center may be stimulated to increased action in several ways. *First*, increased blood pressure in the cranium causes an increased inhibitory action. This may be shown by boring a little hole in the cranium of an animal and then forcing into the cranium some non-irritating liquid. A slowing of the heart beat at once follows. This also explains why in apoplexy the pulse sinks so rapidly. (Apoplexy is due to the bursting of blood

vessels in the brain and the accumulation of blood in that organ.) This may further explain why a person in lying down usually has the rate of his pulse lowered, for in the lying posture the pressure of blood in the brain is, of course, suddenly increased. The fact that such an increase of blood pressure should at once by stimulating the cardio-inhibitory center cause the heart to beat slower, is a very fortunate circumstance, for it reduces the possibility of the rupture of blood vessels and consequent hemorrhages. *Second*, the center is further stimulated by psychic influences. Strong emotions may affect it. Thus, fainting, which is usually due to a flurry of the emotions, results from a stoppage of the heart caused by the inhibitory action of the vagi. When this stoppage lasts but an instant no serious damage results, but when the inhibition has been so violent as to prevent the heart from resuming its beat for even a little while, death may result for lack of circulation. The *third* exciting cause is the lack of oxygen. If venous blood only is allowed to run through the center the rate of pulse is soon reduced and finally stops altogether. This is, of course, the explanation of the observed fact that in cases of suffocation the pulse sinks so rapidly and the heart ceases to beat so soon. *Fourth*, this center may be stimulated by afferent impulses coming from other sensory nerves. A severe blow on the pit of the stomach may cause the heart to stand still for an instant. Here the afferent impulse goes from the sensory nerves of the abdomen to the brain, and there acts in an exciting way on the cardio-inhibitory center. *Fifth*, in addition to these impulses which affect the center directly there are a number of drugs and poisons which act upon the vagus nerve and so affect the beat of the heart. Thus the poison muscarin stimulates the ends of the vagus nerve in the heart and so may bring the heart to a standstill. The drug atropin lames the vagi and so produces an acceleration in the heart beat, while nicotine seems first to stimulate the nerves and so reduce the pulse, then later to lame the nerves and so by weakening the inhibitory influence to increase the rate of beat.

The Depressor Nerves.

It was pointed out previously that along with these inhibitory nerves in the pneumogastric there reach the heart along the same avenue some sensory or afferent nerves. These instead of going to the ganglia are probably distributed between the muscle fibres themselves, and carry to the medulla sensations from the heart. Of course these sensations very seldom reach consciousness and so we are not aware of them, but in the medulla these afferent impulses from the heart affect the centers and bring about important physiological results. In a normal heart about the only sensation that might be expected to come from the heart would be the sensation due to too great a pressure of blood in that organ. Such afferent impulses brought by this nerve to the medulla cause immediate dilatation of arteries all over the body, a condition of things which at once serves to reduce the blood pressure. Artificial experiments confirm this assertion, for if this nerve be cut and its central end, that is the end connected with the medulla, stimulated, a dilatation of the blood vessels over the body occurs and the blood pressure sinks at once. On account of this action this afferent nerve was called the depressor nerve, because the result of its impulses is to depress; that is, to lower the pressure in the arteries. In the rabbit this depressor nerve runs as a separate and distinct nerve to the heart, while in most animals and in man, as already pointed out, it runs along the common pneumogastric trunk.

Cardio-accelerator or Sympathetic Nerve.

In addition to these two extrinsic nerves a third one reaches the heart. This is a nerve which increases the rate of heart beat and is called the cardio-accelerator. This cardio-accelerator has its origin in the medulla and spinal cord, also, but runs from this through the communicating branches to the sympathetic ganglia lying in the lower cervical and upper dorsal region, and from these ganglia reaches the heart. Passing as it does from these sympha-

thetic ganglia this nerve has usually been called the sympathetic nerve. When stimulated it not only increases the rate of the heart beat but for a little while also the strength of the individual beat. In its influence on the heart it is not so pronounced as the vagi, for if at the same instant the vagi and the sympathetic nerves be stimulated the rate of the heart beat is slowed, showing that the vagi are more effective. Just under what circumstances in life these accelerator nerves are brought into play is still not wholly solved. It is probable, however, that the increase in the rate of pulse which follows muscular exercise is due to such sympathetic stimulation.

The Accelerator Center.

These accelerator nerves come from an accelerator center which lies in the medulla, also. This center is called the cardio-accelerator center. It is not in a state of continuous excitation, as in the case of the inhibitory center, but like the latter, it may be excited by stimuli reaching it from other sources. Thus psychic influences such as strong emotions usually increase the rate of heart beat, familiar to everybody in the common experience of having "the heart rise into one's throat." Powerful stimulation of sensory nerves in general may result in a marked quickening of the heart beat. This quickening of the beat, of course, at once raises the arterial pressure and so enables the animal to make sudden and especially vigorous efforts. This arrangement may be but the attempt of nature to put at our disposal for sudden emergencies an increased circulation to make possible increased exertions, and so materially help in the preservation of our safety.

Summary.

By way of summary the innervation of the heart is briefly re-stated.

The beat of the heart itself is due to the automaticity of the muscular substance itself, and also to the automatic

action to the intrinsic ganglia of the heart. These ganglia with their nerves leading to the muscle cells inaugurate the heart beat. To control this heart beat two kinds of nerves reach it from the exterior: first, the vagi or pneumogastric nerves, which because they slow, and if sufficiently stimulated, stop the heart beat, are called cardio-inhibitory nerves. These are normally in constant excitation; and so the heart beat is always a little slower than it would of its own account be. Second, the sympathetic or accelerator nerves reaching it by way of the sympathetic ganglia, the physiological action of which is to increase the rate of the beat.

All these nerves, the intrinsic, cardio-inhibitory and the sympathetic, are concerned in the movement of the heart. They are not sensory. But in addition to these three motor nerves an afferent nerve reaches the heart carrying sensations to the medulla. This afferent nerve, because when it is stimulated by conditions in the heart, it causes a dilatation of the blood vessels in all parts of the body, is called the depressor nerve. The dilatation of the arteries everywhere is, of course, not due to the depressor nerve itself; it simply carries the afferent impulse to the medulla, and from centers in the medulla the impulses to dilate the arteries arise.

Finally, it need not here be noted that these nerves are in pairs, a pneumogastric on each side and a sympathetic right and left.

THE DYNAMICS OF THE BLOOD STREAM IN THE VESSELS.

1.—*The Blood Pressure.* The anatomy and the general distribution of arteries, veins and capillaries have already been given; but there still remains the discussion of the phenomena of the blood in motion. By the beat of the heart the blood is thrown into the arteries, where it accumulates until it reaches a certain pressure sufficient to force it out through the small capillaries at the peripheral ends. The most apparent observation probably in examining an artery

would be the fact that the artery seems to be distended, and the blood in it under considerable pressure. This pressure is, of course, produced by the resistance offered to the flow of blood through the small arteries and capillaries on the one end and the continued pouring in of blood by the heart at the other end. The condition of things differs in no way from that of a city water-works system. In that case the central pump usually forces the water into the mains at such a rate that often a heavy pressure results. Especially so in cases of fire when the central pumps are made to run faster than usual. If there were no resistance at the farther ends of these water mains, no pressure would arise, but the water would flow out at one end as rapidly as it entered at the other. But the pressure in the mains results from the internal resistance due to friction given to the stream as it tries to traverse the smaller pipes at the distal extremity. In such a system with the pump going at a regular rate the pressure in the mains would rise and rise until finally a pressure would result which would be able to force out at its peripheral end as much water in a given time as the pump poured into it at the other end. Thus, in such a system, if in a case of fire the central pump should increase its speed the pressure throughout all the mains would at once rise, and continue to do so until it would be able to force through all the finer ramifications as much water as entered. It is easy to determine what the amount of this pressure is in the case of the blood-vessels. From general considerations which govern the supply of all streams flowing in closed tubes, the pressure must be greatest nearest the heart and become gradually less towards the periphery. Just as in water mains the pressure is greater near the station and gradually decreases toward more distant places.

Arterial Pressure.

The blood pressure in the human arteries has been measured in cases of amputation. Experiments of this kind

in the case of the femoral artery showed a pressure of about 120 millimetres, or about 5 inches of mercury. Experiments on tibial arteries made the pressure higher, results indicating here 160 millimetres, or about $6\frac{2}{3}$ inches of mercury, while the average pressure indicated by a sphygmometer (an instrument which may be used on an artery without injuring it), reaches about 180 millimetres, or 7 inches of mercury, in the case of the radial artery. As the pressure in the aorta must be somewhat greater than in any of these arteries, it is probably not far from 200 millimetres, or 8 inches of mercury.

To more fully understand what is meant by a pressure of eight inches of mercury, comparison may be made with the barometer. Here the pressure of the air is also measured by a column of mercury. As every one knows, the air pressure supports about thirty inches of mercury. As the atmospheric pressure to the square inch is about fifteen pounds it means that every two inches of mercury indicate one pound of pressure to the square inch. Thus, therefore, an arterial pressure of eight inches of mercury means a pressure against every square inch of arterial wall of four pounds. As mercury is a little over thirteen times heavier than water or blood, it means that the arterial pressure would lift a column of blood or water thirteen times eight inches, or not far from nine feet. To state the same thing in still another way, it means that, disregarding friction, blood would spurt from such an artery at such a pressure vertically upward, nine feet.

In the pulmonary artery the pressure is only about one-third of that in the aorta. This relatively low pressure in the pulmonary system is, of course, equally easily explained when we recall that the blood traverses a much shorter distance, and that the lung capillaries are more easily traversed.

Pressure in Capillaries.

The arterial pressure sinks rapidly in the smaller arteries and in the capillaries is very slight indeed. There are

especial reasons why this ought to be so. The capillary walls are exceedingly thin and would not be able to withstand any material pressure, but would be easily ruptured and so disastrous hemorrhages ensue.

Pressure in Veins.

The pressure in the large veins is usually negative, that is to say, there is an actual sucking action. The blood in the veins is not pushed towards the heart from behind, but is sucked up towards the heart by the aspiratory action of the chest, especially in inspiration. If by holding the breath the blood be allowed to accumulate in the veins, there may be produced a temporary venous pressure, especially if by active muscular exertion the smaller veins be compressed and so the blood forced towards the heart. But under normal conditions it seldom reaches a pressure of more than three to five millimetres of mercury, a very slight one compared with the high arterial pressure.

Variation in Arterial Pressure.

The arterial pressure is, of course, immediately influenced by the rate of the heart beat. If the heart beats faster, the pressure rises; if slower, it sinks. Thus, in cases of excitement, when the heart beats fast, the increased pressure resulting therefrom not infrequently leads to the bursting of blood-vessels and apoplexy. Normally when as a result of increased muscular effort the heart is made to beat faster, general experience testifies to an increased arterial pressure.

In the second place the arterial pressure may be varied by the contraction or dilatation of the peripheral arteries. It will be remembered that the arteries especially were provided with a coat of plain muscular tissue. This coat is under nervous control, and by it the arteries are enabled to contract their lumen or to dilate it. It is, of course, at once apparent that a contraction of the small blood-vessels increases the arterial pressure in the same way that closing

the nozzle of a hose at once increases the pressure of the water in it. In fact, the explanation of such a common thing as a cold is found in the fact that, due to a compression of the vessels of the skin, caused as a rule by an exposure to suddenly lowered temperatures, an increased arterial pressure results and the blood is driven in undue amounts through the vessels of the interior organs which are thereby congested and an inflammation results which we designate as a cold.

In the third place, there is a slight variation produced by the rhythmic beat of the heart. It is easily understood how the sudden injection of a ventricle full of blood into the arteries will cause the pressure in them to rise a little, while during the diastole of the heart as the blood is continually flowing out into the capillaries the pressure tends to sink a little. This variation is, however, very slight, amounting to little more than a few millimetres of mercury. As the average pressure of the aorta is as much as 200 millimetres of mercury, the periodic rise and fall of but a few millimetres causes practically no effect.

*THE CHANGING OF THE INTERMITTENT FLOW FROM THE HEART
INTO THE CONSTANT FLOW OF THE CAPILLARIES.*

If capillaries like those in a frog's foot be examined and the blood be seen circulating through them, it may be noticed that the blood flows smoothly and regularly, showing no pulsations. Even through the smaller arteries the blood stream seems to all external appearances to be perfectly constant and regular. As the blood is, however, poured into the arteries by the heart in periodic pulsations the question arises, how such an intermittent flow is changed into a regular and continuous one. This is readily explained if it be remembered that the real force which drives the blood from the arteries into the capillaries is the force exerted by the elastic walls of the arteries which are much distended and which in trying to regain their original dimensions press upon the contained blood. Much as water

may be compressed by forcing it into a hose of very elastic rubber and then closing both ends. If slight openings into such a distended rubber hose would be made, the water would at once be forced out by the elasticity of the walls.

The pressure of the blood, which, of course, is but the amount of compression due to the elastic walls, is, as has been stated, 200 millimetres of mercury, or four pounds to the square inch (in the aorta). It is this pressure which forces the blood onward. Even when the heart is not beating at all, the pressure still continues in the vessels keeping the stream in motion. When the heart throws in its amount of blood at each beat this arterial pressure is raised but very little, only three to four millimetres. Such a slight change in the pressure would not affect the flow through the capillaries at all, any more than the fluctuation of a few pounds of pressure in the central pump of a water-works station could be detected by the individual who is watching the stream issue from the nozzle of his hose in a distant section of the city.

THE RATE AND TIME OF THE BLOOD FLOW.

1.—*Rate.* The rate at which the blood moves forward in these vessels varies at different points along its course. It is fastest near the heart and becomes gradually slower towards the peripheral ramifications. This different rate of flow, is, of course, compensated by the fact that the combined lumen of the arteries and veins becomes gradually larger as we approach the periphery. This is easily understood by watching the flow of water in a river. Where the river is wide the flow is sluggish, but where the banks of the river approximate each other the river may have quite a swift current. Thus, the forward motion of the water on Lake Erie is probably not perceptible, but when the forward flow of the lake becomes narrowed between the banks of the Niagara River it may be changed into a torrent. The fact that the blood does not flow as rapidly in the veins as it does in the arteries is due to the same thing, the veins being correspondingly larger.

While it has been impossible to measure the exact rate of flow in the vessels in man, repeated experiments have been made on the lower animals, and certain inferences have been drawn from them with reference to the condition of things in the human body, which are probably not very far from the truth. Such calculations show that the blood in the human carotid flows about 400 millimetres, or sixteen inches in a second. In the smaller arteries it is, of course, less, while finally in the narrow capillaries the blood moves through a distance of about $\frac{1}{30}$ of an inch only in a second. As capillaries in a very general way are about $\frac{1}{30}$ of an inch long, it means that it takes the blood about one second to traverse them. In the larger veins the rate is from 100 to 125 millimetres, that is, from four to five inches per second. This rate may be much modified by variations in the energy of the respiratory movements. As in the case of the smaller arteries, so with the smaller veins, the rate is much slower than four inches.

2.—*Time.* These measurements of the rapidity of the flow have been made on the lower animals by interpolating between the cut ends of the vessel some form of bent glass tube through which the gradual streaming of the blood could be visible throughout. As the rate of flow is different for nearly all portions in the course, it is impossible by this means to calculate how much time would be required for the blood to make its round through lung or tissues. It is, however, possible to make such determination and to discover very accurately the exact amount of time it takes a drop of blood to pass through the routes of circulation. Thus, if some substance which could easily be detected be injected into the carotid artery of a horse and the re-appearance of such injected substance watched for in the blood returning from the jugular veins, the time to traverse the circulation between these two points would be at once given. Experiments of this kind on lower animals and calculations from these to the human body show that on an average the time required for the blood to make one com-

plete circulation is about thirty-two seconds. Of this time about nine seconds are lost in passing through the pulmonary circulation, the other twenty-three through the systemic.

The real rapidity with which the blood moves may, therefore, be readily appreciated from this when we remember that a corpuscle of blood might in the course of such a short time as one hour carry 120 loads of oxygen to the head. It means that the entire amount of blood in the body is moved in a period of time no greater than one minute twice over the entire course of circulation. If one should fancifully try to calculate how many loads of oxygen on an average a red corpuscle would carry in the course of a month, the figures would no longer be comprehensible; while if the calculation should be extended in computing the actual distance which such a corpuscle had covered in this vast number of trips the result might possibly be comprehended only when reduced to miles.

In this connection it may be well to repeat that this whirl of blood is mainly for the purpose of carrying in an uninterrupted flow the supply of oxygen to all parts of the body, and only incidentally to carry the nourishment and to remove the waste, even though these two latter are, of course, indispensable.

THE PULSE.

1.—*Cause of Pulse.* The sudden injection of several ounces of blood at each beat into the aorta causes the walls of the aorta to be additionally distended right at the heart in order to make room for this new amount. This expansion at the origin of the aorta is made possible by the elasticity of its wall. But by this elasticity the walls, distended so suddenly, try to regain their original position, and in so doing start a wave along the artery familiar to us all as the pulse, much like a pebble thrown into the water will start at that point a series of waves running in every direction. Of course in the case of the aorta, the only direction possible is toward the periphery.

2.—*Rate of Speed of Pulse.* This wave runs at a definite speed along the arteries, which is in man about twenty-five or thirty feet per second. This rate shows that a pulse wave runs out at its peripheral end and is over before the succeeding one is inaugurated. This wave must not be understood as an actual forward movement of the blood, but is a mere pressure wave, just as in the motion of waves on a surface of water, the water itself does not move forward with the waves, but moves up and down in almost the same place, as is indicated by observing any floating object which does not travel along with the wave at all.

3.—*Kinds of Pulses.* An examination of the pulse wave enables the practiced physician to learn much about the state of things in the general circulation. Thus, a physician can distinguish four different kinds of pulses: First, the *pulsus frequens*, or the *pulsus rarus*, depending on the number of heart beats per minute. Second, the *pulsus celer*, or the *pulsus tardus*, depending on the quickness with which a single beat is accomplished. It indicates whether in the individual beat of the heart the ventricles contract energetically or slowly. This must not be confounded with the rate of the pulse or the *pulsus frequens*, for the heart might beat but fifty times a minute, say, a very slow rate, and yet perform each beat with a quick, jerky systole. Third, the *pulsus magnus*, or the *pulsus parvus*, depending on the amount of blood which is thrown into the arteries at each beat. A *pulsus magnus*, or big pulse, would be indicated by the increased size of the artery in question, while a *pulsus parvus*, or small pulse, would be indicated by a more or less collapsed artery. Fourth, the *pulsus durus*, or the *pulsus mollis*, that is, a hard pulse or a soft pulse, depending on the amount of pressure necessary to completely compress an artery, and so prevent the blood from flowing past the point of compression. In other words, the pulse is hard when the pressure of blood is high and vice versa. Here, also, a hard pulse must not be confounded with a big pulse. Thus it is possible to conceive

a condition of things in which a greatly increased peripheral resistance in the arteries should arise and produce a hard pulse, and yet the heart itself might force but a small amount of blood into the artery at each beat and so indicate a small pulse at the same time.

4.—*Physiological Measurements of the Pulse and Arterial Pressure in General.* Every one knows that the pressure in the arteries may be easily determined by feeling it with the finger. The rhythmic variation in arterial pressure which we call the pulse, is commonly examined in this way. But in order to show with much finer detail all the phenomena of arterial pressure, various forms of sensitive instruments have been devised. Possibly the most satisfactory one is the sphygmograph. This consists essentially of a sensitive recording lever placed on the artery in such a way that any increase in the pressure of the artery will raise the lever. The lever itself is then arranged to write on some suitable moving surface and so a curve of pressure is obtained. The philosophy of such an instrument is almost too simple to need further explanation. Every one knows that by putting the finger on the pulse we feel the wall of the artery rise. In fact, this rising we called the pulse. If, now, instead of the finger a sensitive lever be placed on the artery, it is, of course, easy to see that at the moment the pulse wave is under the lever it will lift the lever, and if the distal end of the lever is provided with a recording point

Fig. 85.—SPHYGMOGRAPHIC CURVES, FROM HUMAN RADIAL ARTERY.

a curve will be the result. The sphygmograph possesses the great advantage that it can be used easily and without any injury to the blood vessels, and so is adapted for the

study of the pulse of man himself. In Figure 85 there are indicated such sphygmograph curves.

On animals there is more generally used an instrument called the kymograph. This is in principle a revolving drum run by clockwork on which the recording lever traces the desired curves. This lever rests on the mercury in one limb of a U-shaped tube, while the other limb of this U-shaped tube (*D* in Figure 86) is directly connected with the cut end of the artery to be examined. To prevent the blood from touching the mercury there is put over it in that part of the tube some liquid which will prevent the blood from clotting. Upon connection with the artery the pressure of the blood of course at once forces the mercury down one limb of the tube and necessarily up in the other, but as the recording lever moves up and down with the mercury on which it rests it records all these variations in pressure. An examination of the figure of the kymograph will easily show how a slight increase of arterial pressure will at once cause the recording lever to be raised, while a decrease at once lowers it. On the revolving drum this recording lever will of course then describe curves such as those pictured in Figure 86, which reproduce in excellent detail for permanent study all the variations of pressure in the artery examined. On such kymograph tracings as those traced on the drum in the figure here given, the small curves indicate the individual pulse waves, or what is the same thing finally, the heart beats, while the larger waves indicate the movements of breathing. In the case of a dog the arterial pressure rises through inspiration and sinks during expiration. The explanation of this periodic respiratory rise and fall of arterial pressure is not yet possible, nor has it been definitely proved that it exists in man. If we, therefore, since we do not understand fully these respiratory curves, turn our attention to the pulse waves themselves, each is seen to consist of a straight and rapid rise of pressure to a maximum height, while the fall of pressure, or the downward wave, is not at all straight and gradual. There is

placed on the descent a second smaller wave, and in some instances a third. The second wave, however, like a notch

Fig. 86.—LUDWIG'S KYMOGRAPH.

A, revolving drum to receive tracings; *B*, pendulum of the clockwork to rotate drum; *C*, the U-shaped mercury tube; *D*, where connection is made with the blood vessel to be examined; *E*, *F*, the piston raised or lowered by the mercury on which it rests; *G*, the recording lever.

on the descending part of the curve, is always present. This presence of two crests on the pulse wave has given to it the name of *dichrotic*. The explanation of this second or smaller wave superposed on the first, is still not wholly satisfactory. Various suggestions are offered by different physiologists, but the probability is that the second wave is due to the reflection of the pulse wave against the semilunar valves.

To explain this more fully let us picture the condition of things just at the moment the ventricle forces its contents into the aorta. Here, in order to make room for the sudden addition, the aorta expands close to the heart, which expansion then in the form of a wave proceeds from that point to the periphery; but, like the waves caused by a pebble in the water, they would naturally run in all directions, and so the pulse wave would start to run back towards the heart. But scarcely started in that direction, it would meet the closed semilunar valves and be there reflected backwards on the heels of the original pulse wave and run with it to the tips of the arteries. Just as a loud sound proceeding in a certain direction might have upon its heels a slight echo caused by some precipice just behind.

THE INNERVATION OF THE BLOOD VESSELS.

Many experiences and observations show that blood vessels have a nervous control separate from the control of the heart. Thus, blushing with embarrassment, or turning pale with fright, or becoming flushed with exercise clearly indicate that nerves must affect the contraction and dilatation of arteries. The fact that arteries have muscular tissue in their walls makes such a contraction or dilatation intelligible, and no doubt the nerves in question reach these muscles. Experiments have not failed to disclose such nerves which, when stimulated, cause the arteries either to contract or expand. Being thus concerned in controlling the motion of the muscles of the arteries, they are called *vaso-motor nerves*. In their physiological effect these *vaso-motor*

nerves are of two kinds; first, vaso-motor nerves which when stimulated cause the arteries to contract — the vaso-constrictor nerves; second, vaso-motor nerves which when stimulated cause the arteries to dilate — vaso-dilator nerves.

1.—*Vaso-constrictor nerves.* The vaso-constrictor nerve fibres are found in almost every part of the body. They seem in a continued state of excitation, keeping the arteries to which they go constantly contracted, for when such a nerve is cut the arteries affected at once dilate. The explanation of this is found in the fact that the cutting of the vaso-constrictor nerves puts an end to the tonic influence which they possess and the arteries freed from their control expand to their natural dimensions. Why the arteries should be kept continually contracted is not hard to understand. There are times when certain organs of the body in order to do special work need an extra supply of blood. The stomach needs more blood during digestion than when idle between meals. Now, by keeping the gastric arteries in a tonic or continued contraction they may be dilated by relaxing the muscles when the process of digestion begins. As arteries cannot forcibly expand (muscle fibres can never be made to expand forcibly), they must be contracted regularly in order to make an expansion when desired possible. While cutting a constrictor nerve causes a dilatation in the vessels affected because, as already stated, the tonic control is cut off, a stimulation of the nerve causes an increased contraction in the artery supplied. If in a rabbit the constrictor nerve going to the transparent ear be stimulated, the ear flap at once becomes pale.

Distribution of Vaso-Constrictor Nerves.

The course of these constrictor nerves throughout the body is about as follows: First. In the head they arise in the medulla, pass from this into the sympathetic ganglia of the neck, from which they proceed to all parts of the head, usually running along with the cranial nerves. The trigeminal nerve, especially, is rich in such constrictor fibres.

Second. The constrictor nerves of the chest and abdomen take their origin in the medulla, also, then through the spinal cord they reach the sympathetic ganglia of the chest and abdomen by means of the communicating branches, and from these ganglia they proceed to the visceral organs. The constrictors going to the organs in the abdominal region go mainly through the large splanchnic nerves and the solar plexus from which they spread in all directions. As there are so many and such large arteries in the abdomen this splanchnic nerve is probably the most important constrictor nerve in the body. Third. Constrictor nerves going to the trunk and the extremities arise in the medulla, also, pass down the cord and through the communicating branches reach the sympathetic ganglia. From these they rejoin the spinal nerves and with them are distributed at the periphery. It will thus be seen that all the constrictor nerves arise in the medulla, but that before reaching their destination they pass through sympathetic ganglia. For this reason they are often called sympathetic nerves.

The Vaso-Constrictor Center.

These nerves are governed by a center which lies in the medulla where they originate. This center is automatic, and is in constant excitation, and so, as stated before, there is a continued contraction in all the arteries supplied. But this *vaso-constrictor* center may be inhibited in part, that is, it may be prevented from keeping the arteries contracted. Such an inhibition would, of course, result in a dilatation of the arteries affected. In this way the blood supply of the visceral organs, especially, is largely controlled. What, now, are the influences that inhibit this center and so cause a dilatation?

First: Psychic influences inhibit it. The explanation of blushing lies in the fact that psychic influences (embarrassment, shame, etc.), reach that part of the center controlling the arteries of the face and inhibit it, and the

muscles freed from their regular control relax and expand to their natural dimensions.

Second: Different afferent nerves may inhibit it. When food enters the stomach the sensory impulses reaching the brain from the stomach inhibit that part of the vaso-constrictor center which governs the gastric arteries, and these removed from the tonic stimulus to remain contracted dilate, and so the mucous gastric membrane becomes red and flushed with blood.

Third: This vaso-constrictor center is very energetically inhibited by impulses reaching it from the depressor nerves of the heart. As stated in a former paragraph, this nerve is probably normally stimulated when the pressure of the blood in the heart (and so, of course, elsewhere), becomes too great. Such impulses on reaching the vaso-constrictor center in the medulla forcibly inhibit it, and an immediate dilatation of arteries results, the consequence of which is that the blood pressure at once sinks. Such a general sinking of blood pressure is usually accomplished by having that part of the constrictor center inhibited which governs the abdominal viscera, and which at once arrests the tonic action of the splanchnic nerve. As a result of this the many large and small arteries through stomach and intestines, etc., enlarge, the blood streams through, and the arterial pressure is relieved. On the other hand, to stimulate the splanchnic nerve, that is, to make this tonic action stronger and so produce an increased contraction, may diminish the size of the abdominal blood-vessels to such an extent as to press out of them as much as twenty-seven per cent. of their contained blood supply. The efficiency of and the necessity for such a nicely regulated control of the blood supply for the various organs is, of course, quite apparent.

Under some circumstances this constrictor center may be actually stimulated. Thus, turning pale with fright is due to the flurried stimulation of its activity.

2.—*Vaso-dilator nerves.* In addition to the vaso-constrictor nerves there are vaso-dilator nerves. These nerves are not, however, in a state of tonic excitation, but are brought into play at special times only. Thus, when a voluntary muscle is made to exercise, the arteries supplying that muscle at once dilate. This might at first seem due to an inhibition of that part of the constrictor center governing the arteries of these muscles, but there can actually be found nerves which when stimulated cause a direct dilatation. These dilator nerves come from the cerebro-spinal system and are most apparent in the voluntary muscles and numerous glands (submaxillary and parotid). They run to the intrinsic ganglia distributed through the muscular coat of the arteries (to which also the vaso-constrictor nerves run) and here inhibit the action of these vaso-constrictor nerves, the result of which is, of course, a dilatation. They run along with the trunks of the cranial and spinal nerves, and anatomically are not distinguishable from them. When the spinal nerve going to the muscle is cut and the peripheral end stimulated not only does the muscle contract, but the artery in the muscle dilates. Such dilator nerves serve as additional means to regulate the local supply of blood, and in the case of muscles, probably accompany the motor nerves so that the best activity of the muscle would be made possible by simultaneous increase in the supply of blood to it. The vaso-dilator center lies in the medulla, also, but seems not to play such an important role as the constrictor center.

3.—*Comparison of the innervations of the heart and blood vessels.* There is a striking homology between the nerves of the heart and the blood vessels.

1. Both have distributed in their muscles intrinsic ganglia.

2. To both there run nerves, the stimulation of which causes an increase in the contraction. In the case of the heart this nerve is called the cardio-accelerator, and causes

the heart to contract more rapidly. In the case of the vessels it is the vaso-constrictors. These nerves, as already stated, when stimulated cause an increased contraction here. In the case of the heart, as well as the vessels, these nerves come directly from the sympathetic system, although they take their real origin in the cerebro-spinal system.

3. Both heart and vessels are supplied with nerves which inhibit; that is, nerves, a stimulation of which causes a reduction in the amount of contraction. In the case of the heart this inhibitory nerve is the vagus, pneumogastric, or tenth cranial nerve. In the case of the vessels it is the vaso-dilators. As the vagus causes the heart muscle to relax, so the dilators cause the arterial muscles to relax. In both cases they are cerebro-spinal nerves and reach their destination without the intervention of the sympathetic system.

4. The heart is supplied with an accessory nerve called the depressor, which carries to the medulla sensations from the cardiac muscle. While, in the case of the vessels no such a typical sensory nerve exists, there are, of course, distributed to them nerves of general sensation, by means of which sensory impulses from them reach the brain.

CHANGES IN THE CIRCULATION WHICH OCCUR AT BIRTH.

It is evident that the lungs are not functional before birth. The blood must, therefore, seek its fresh supply of oxygen elsewhere. This has necessitated the blood taking a somewhat different course up to the moment of birth from the one it retains ever after.

The foetus not only gets its nourishment, but its oxygen supply also from a structure known as the placenta, or "after-birth." This is a structure which grows out from the foetus and intertwines itself closely with the uterine wall; so closely, indeed, that the nourishment in the blood flowing through the uterus may seep across into the foetal capillaries of the placenta, and along with it the oxygen carried by the arterial blood of the mother passes through

the capillary walls and is taken up by the foetal red corpuscles. There is, of course, no mixing whatever of the maternal and foetal bloods. The two remain perfectly distinct, and the transfer of nourishment and oxygen is made through the delicate capillary walls. This placenta is, therefore, the foetal lung. Running to this placenta through the umbilical cord or naval stalk from the foetus is a large artery arising from the abdominal aorta. This carries the blood from the foetus to the placenta. Here it passes through the placental capillaries and is gathered up in the veins and brought back to the foetus through the umbilical cord by the umbilical vein. This, although called a vein, contains arterial blood, having just received in the placenta both its new supply of nourishment and oxygen. Upon reaching the foetus this umbilical vein flows through the liver, and from the liver the blood reaches the ascending vena cava, by means of which it is carried to the right auricle. This pure blood, going through the vena cava in the way just described, does not drop from the right auricle into the right ventricle, but goes from the right auricle at once into the left auricle through an opening in the auricular septum called the foramen ovale. The course of blood in this direction is facilitated by a peculiar flap or valve on the right auricle so placed that it guides the current of blood across into the left auricle. This little flap is called the Eustachian valve. This transfer is materially aided by the fact that the ascending vena cava flows around to the back of the right auricle before emptying into it, and so has its opening close to the auricular septum. The pure blood so transferred to the left auricle now drops into the left ventricle, and by its systoles is forced out through the aorta. For reasons to be pointed out in a moment, most of this pure blood goes to the head and neck through the innominate and carotid arteries. Thus, these rather more important portions of the body are supplied with the best available blood.

From these regions, that is from head and neck, the blood is again gathered up by veins, and finally by the vena cava descending, carried to the right auricle. But here this current of venous blood is so poured into the right auricle that it does not meet the current of pure blood flowing through it to the left auricle. The descending vena cava opens into the auricle at the opposite side and from above, and in this way the stream of venous blood which it bears at once drops through into the right ventricle. This crossing of two streams, one arterial and one venous in the right auricle, may be easily understood by showing how readily one might construct pipes leading into a room in such a way as to have two currents flow through it and yet have them separate and distinct; having one, for instance, in one corner drop into the room from above, into a collecting funnel below, while the other stream might at an opposite corner be carried across from one wall to another independently of the former, especially if a flap or plank like the Eustachian valve should be added.

The stream of venous blood having reached the right ventricle in the manner described, is now by the systole of the right ventricle forced out into the pulmonary artery, and would naturally go to the lungs; but the lungs do not at this time contain air. They are collapsed, and it would be almost impossible and entirely useless to force this stream of blood through them. This difficulty is remedied, however, by a communicating branch which connects the pulmonary artery with the arch of the aorta, and so enables the venous blood to pass from the pulmonary artery through this connecting duct into the descending aorta. This connecting duct is called the duct of Botallus. As this duct of Botallus reaches the aorta after it has given off its vessels to the head it prevents the flow of this venous stream in that direction. But this venous stream, together with a little pure blood which finds its way through the arch of the aorta from the left ventricle, descends through the aorta, and while a little of it is carried by arteries which supply

the posterior part of the body, most of it is again by the umbilical artery carried to the placenta, there to have its oxygen supply renewed.

At the moment of birth a number of changes occur. The circulation of blood through the placenta is stopped, and now with the first breath drawn into the lungs these organs expand and allow the stream from the pulmonary arteries to pass through them. Within a few hours the opening from one auricle into the other begins to be closed up, and the duct of Botallus becomes filled by depositions of fat and connective tissue in its lumen. The stumps of the umbilical artery and vein practically disappear, and the circulation which is to be maintained throughout life is established. It, however, not infrequently happens that the opening in the auricular septum remains through life, and in some cases even the duct of Botallus remains open. Such individuals, must, of course, have their circulation materially interfered with. The Eustachian valve in the heart becomes almost obliterated, although even on an adult heart traces of it, as well as the thin partition closing the auricular septum, and the solid string, the remains of the duct of Botallus, may still be readily seen. In this rather remarkable way, without a break, the foetal circulation becomes changed in a moment into the regular circulation of the fully developed body.

CHAPTER IX.

THE LUNGS AND THE PROCESSES OF RESPIRATION.

The circulation of the blood treated in the preceding chapter leads naturally and without a break to the consideration of the phenomena of respiration. It was pointed out that the main reason for the mad rush of the blood is to carry out the functions of respiration. Respiration consists essentially in two gaseous interchanges. One of these takes place in the lungs. Here oxygen is taken up by the red corpuscles and carbon dioxide thrown off from the plasma. The second gaseous interchange occurs in the tissues of the body and is the exact reverse of the first, for here the oxygen is liberated and the carbon dioxide picked up.

These two respiratory interchanges are complementary. The one in the lung is called *external respiration*, the one in the tissues *internal respiration*. We are first concerned with the processes as they take place in the lungs.

THE ANATOMY OF THE RESPIRATORY SYSTEM.

The principal structure concerned in external respiration is the lung. Into this air is drawn through the mouth and nostrils by way of the trachea. At the upper portion of the trachea where it leads into the pharynx is a dilatation called the "voice-box." Here by suitable arrangements the outgoing air sets into vibration stretched membranes which produce the sounds of speech. For a detailed description of this organ, the voice-box, or larynx, the student is referred to a subsequent chapter on "The Voice."

The windpipe, or *trachea* as it is called, may be easily felt by placing the finger on the throat. The large dilated portion is the voice-box just noted, while the tube extend-

ing downward from that is the trachea proper. This consists essentially of a dense fibrous tissue in which are imbedded horseshoe-shaped pieces of cartilage which serve to

Fig. 87.—THE AIR PASSAGES AND LUNGS FROM BEFORE. LUNG TISSUE REMOVED ON RIGHT LUNG TO SHOW RAMIFICATIONS OF BRONCHIAL TUBES.

a, larynx; b, trachea; d, bronchial tube.

keep the trachea open. The open ends of these horseshoes are backward, that is, next to the gullet, and the absence of bands of cartilage here no doubt materially facilitates swallowing.

The trachea is lined on the inside with several layers of epithelial cells, of which the innermost layer is ciliated. These cilia move in regular rhythm and in such a way that any material resting on them is driven forward toward the mouth. In this way the mucus, or phlegm, is removed. The trachea at its lower end divides into two branches, called the bronchial tubes, and these in turn divide and subdivide repeatedly until finally a perfect system of ramifications of tubes is the result. At the end of each of these finer ramifications there is a sack-like dilation called the alveolus. The wall of this alveolus is thrown into little pouches, each pouch being called an air cell. It is necessary to remember here that the term "cell" is not used in

its scientific sense, but in the original sense it had, meaning a little chamber. In this way one single alveolus may, by

Fig. 88.—CILIATED EPITHELIUM FROM THE TRACHEA OF A RABBIT. (After Schäfer.)
 m^1 , m^2 , m^3 , mucus-secreting cells lying between the ciliated cells.

the folding of its walls, give rise to a great many air cells. In the walls of these air cells run the pulmonary capillaries, and at this point the gaseous interchange of the blood takes

Fig. 89.—DIAGRAMMATIC REPRESENTATION OF THE TERMINATION OF A BRONCHIAL TUBE IN A GROUP OF ALVEOLI. (After Schäfer.)

B, bronchial tube; *L. B.*, bronchiole; *A.*, atrium; *1*, Alveolus; *c*, *c*, individual air cells.

place. The anatomy of the bronchial tubes and their finer divisions does not differ materially from that of the trachea. The cartilaginous rings, however, become less regular and

there is a gradual thinning out of the inner epithelium, which in the final branches is reduced to a single layer of ciliated cells. In the alveolus, finally, the wall is made up of elastic tissue lined on the inside by a single layer of flat epithelial cells. The very small bronchial tubes possess a little plain muscular tissue, so that they are actually able to contract and expand, and thus reduce or increase the amount of air which reaches the alveolus. The space between the alveoli and the branches of the bronchial tubes is filled with connective tissue, through which nerves, arteries, and veins pass.

Fig. 90.—SECTION OF LUNG, SHOWING SEVERAL CONTIGUOUS ALVEOLI, WITH THE BLOOD-VESSELS IN THE SAME INJECTED. (After F. E. Schultze.)

a, a, c, c, partitions and edges of alveoli; *b*, artery giving off capillaries.

The lung is covered on the outside by a delicate serous membrane, called the *pleura*. This surrounds the lung closely at all points except at the root of the lung, the point where the arteries and veins, and bronchial tubes enter it, at which point the pleura is reflected and lines the inside of the chest wall.

PATHOLOGICAL CONDITIONS OF THE RESPIRATORY SYSTEM.

While there is not a single system in the body which is immune from the attacks of disease, and though in many individuals the respiratory system is among the most invulnerable, yet the general fact remains that this system more than any other becomes the seat of pathological conditions. This system is especially apt to become congested and inflamed as a consequence of exposure to cold. When this inflammation is limited to the trachea, the bronchial tubes and its larger divisions, we speak of it as a mere cold on the chest, or *bronchitis*. As a consequence of a congested condition of the respiratory mucous membrane it frequently becomes sore, and is marked by an excessive secretion of mucus, often to such an extent as to more or less clog the passages. This excessive mucus is, of course, the familiar *phlegm*, which forms such an annoyance of an ordinary cold. Possibly the meaning of this extra mucous secretion may be found in the fact that it acts as a kind of protection to the inflamed membrane beneath, and serves to prevent the introduction into that membrane of foreign particles, be they ordinary grains of dust or more injurious germs. This phlegm is, therefore, figuratively speaking, a kind of natural salve which nature puts over these congested portions to prevent the danger of exposure to foreign elements.

This congestion may also extend into the air passages of the nose and so produce the familiar "cold in the head," and as the mucous membrane of the pharynx is continued into the middle ear through the Eustachian tube, that organ is frequently drawn into the inflammation. When such a congestion of the nasal passages continues and becomes the seat of ulcerations, it leads to the too-common *catarrh*. But the term "catarrh" is not, strictly speaking, confined in its application to a chronic inflammation of the nasal passages. The term "catarrh" means inflammation, and in such a sense is applied to an inflammation wherever it may occur. Thus, bronchitis is but a catarrh of the bronchial

tubes. An inflammation of the mucous membrane of the stomach is called a "catarrh" of the stomach, while even an inflammation of the eye due to exposure is spoken of as an ophthalmic catarrh.

As long as the inflammation is confined to the larger air passages no especial danger ensues. But this inflammation may become extended into the alveoli of the lung. This condition is a much more serious one, and is called *pneumonia*. Colds, catarrh and pneumonia are not, however, mere congestions. If they were, the effects of the congestion ought to disappear when the proper vascular supply is re-established. These diseases owe their dire results to the infection of germs. The bacterium of pneumonia has been recently, actually, quite satisfactorily isolated. Arctic explorers report their perfect immunity from colds in regions which are free from bacteria. We must look upon the congestion of the air passages or lungs more as a favorable circumstance for bacterial infection, which infection once having secured a foothold, produces the real disease. That the resistance of the respiratory organs to germs is materially weakened in congestions is attested by the relative ease with which consumption is induced in weak persons, as a consequence of a "cold."

The pleura, also, may become the seat of inflammation, giving rise to a disease called *pleurisy*.

The smaller bronchial tubes near to where they open into the alveoli, possess in their walls some plain muscular fibres. Ordinarily these are relaxed and so free access of air is permitted to the alveoli. But under certain conditions these muscles go into a tonic contracted state, thus materially reducing the quantity of air which is able to get into the alveolus and so making it difficult for the person in question to get a sufficient amount of air. This condition is called *asthma*.

Finally, the most serious pathological condition of the lung is *consumption*. This, as has been pointed out, is a disease which is due to the ravages of bacteria living in that

organ. When we remember that on an average about every one person in seven is afflicted with this disease, that it carries off as its prey more people than pretty nearly all of the more violent contagious diseases combined, and when we remember that by improper ventilation, the crowding of persons into close rooms, this disease is highly communicable, we are more than justified in every reasonable effort to prevent its spread, and especially its spread to children, who, on account of their age, may yet happily be free from its fatal touch.

THE MECHANICS OF RESPIRATION.

1.—*Movements of Respiration.* In order for the blood to be continually supplied with fresh oxygen it is necessary that this gas should be constantly renewed in the lungs. This renewal is brought about by the movements of respiration. The essential feature of all the movements of inspiration is an enlargement of the chest. By enlarging the chest additional room is made, and the air rushes in from the outside to occupy this extra space. Just as in an accordion when it is drawn apart, air streams into it through the various valves made for that purpose. Or, as in the case of a pump, when the piston is lifted, and so additional room made in the pump cylinder, the water under the pressure of the atmosphere rushes in to fill this extra space. This enlargement of the chest may occur in three different ways.

First, it may be enlarged in an up-and-down direction. This is accomplished by the contraction of the muscles of the diaphragm. The diaphragm is a dome-shaped structure with the dome or convexity extending chestward. By the contraction of the muscles in this dome it is pulled downward, the dome becomes flattened and the chest cavity enlarged a corresponding amount.

Second, the chest may be enlarged by increasing its dimensions in a forward-back direction. This is done by raising the breast bone. By noting the skeleton it may be

seen that the breast bone is connected with numerous pairs of ribs which extend from the breast bone backwards and upwards. If, now, by proper muscles these ribs are raised, the result will be that not only the breast bone will move upward, but also forward. This may readily be exemplified by joining both hands and letting them rest in front on the pelvic region. If, now, the arms be raised up, not only are the hands raised, but they are also pushed away from the body, and when the arms are extended directly forward may be almost two feet or more from the trunk, whereas in their original position they rested immediately against it.

A third enlargement of the chest is the lateral enlargement. This is brought about by the fact that not only are the ribs lifted up, but they rotate outward. This enlargement may be illustrated in the example of the raising of the folded hands also. If, in addition to the lifting of the hands, as in the preceding illustration, the arms be somewhat bent and rotated outwards, it is at once apparent that the lateral diameter is increased.

While an inspiration results from an enlargement of the chest, an expiration is due to a contraction of the chest. Under ordinary circumstances an expiration is a passive process. We expand the chest and take air in by an active contraction of muscles, but we expire by simply relaxing the muscles and letting the chest drop back to its natural dimensions. Sometimes, however, the expiration may become forced. This may be accomplished in three different ways, which are the exact opposites of those given for enlarging the chest. That is, the diaphragm may be pushed up further into the chest and become more dome-shaped than before. This is done by contracting the abdominal muscles and so pressing the stomach, liver and intestines up against the diaphragm, and in this way lifting it up. Or, a forced expiration may result from pulling the breast bone downwards and rotating the ribs inward.

It is unnecessary to say that generally all three ways are used at the same time, although the breathing of men is

more largely with the diaphragm, while that in women is more largely with the ribs.

The muscles that move the ribs up and down are called the *intercostal* muscles. Of these muscles there are two sets, the external intercostals and the internal intercostals. The external intercostals are so arranged that the insertion point on the lower rib is always forward from the insertion on the upper rib, while in the internal intercostals the reverse is true. To show how the contraction of the external intercostals raise the ribs and breast bone, while the

Fig. 91.—DIAGRAM TO ILLUSTRATE THE MANNER OF ENLARGEMENT OF CHEST.

internal intercostals pull it down, a little piece of apparatus may be constructed such as the one indicated in the accompanying diagram. If, now, a piece of rubber be stretched in such a way as to correspond with the pull of the external intercostals it will raise the bars. When arranged like the internal intercostals it will pull it forcibly downwards. That such would result is of course easily seen by studying Figure 92. The line $a'b'$, corresponding to the external intercostals is shortened, which, of course, is analogous to the contraction of the muscle itself. Shortening can take place only when both beams are pulled upward, while the exactly opposite is the result with the internal intercostals.

2.—*The Rate of These Movements.* The rate at which inspirations follow each other varies considerably under different circumstances, but on an average in an individual

who is not conscious that his breathing movements are being observed, the rate is from fifteen to twenty per minute. It is greater in children, and in infants is on an

Fig. 92.—DIAGRAM TO SHOW THE OPERATION OF THE EXTERNAL AND INTERNAL INTERCOSTAL MUSCLES.

R, R'', r, r'' , ribs in elevated position; R, R', r, r' , ribs in depressed condition; a, b , external intercostals; a', b' , same contracted elevating the ribs; d', c' , internal intercostals; d, c , same contracted depressing ribs.

average as high as forty-four. From this it gradually sinks during childhood until the adult rate of fifteen to twenty just given is reached. This rate, however, may be much influenced by emotions, by muscular exercise and by temperature.

3.—*The Capacity of the Lungs.* The capacity of the lungs no less than the rate varies with different classes of people, and even with individuals of the same class. On an average, however, in a properly exercised person the following figures do not come very far from the actual condition of things:

If a person breathe out as much air as he can possibly do, or, in other words, if he reduce the capacity of his lungs as far as he is able to do, he still has in his lungs a considerable amount of air. During life it is impossible, of course, to get the lung perfectly air-free, and so the amount of air which is left in the lung after the most forced expiration possible, can be measured only after death. Experiments of this kind give about 1,640 centimeters, or

about 100 cubic inches as the amount of air which it is impossible, even by the most violent expiration, to remove. These 100 cubic inches are called the "residual" air. But in ordinary respirations we do not breathe out as much as we can, and under these circumstances there is left in the lung 1,640 centimeters, or 100 cubic inches additional. That is to say, in ordinary breathing there are in the lung at the end of an expiration 200 cubic inches of air. These extra 100 cubic inches are called the "supplemental" air, which, together with the residual air, forms the "stationary" air of 200 cubic inches. Now, at an ordinary breath we take in about 500 centimeters, or 30 cubic inches, and of course breathe out the same amount at an ordinary breath. This air is called the "tidal" air. But we are able by a forced inspiration to take in more than we do ordinarily. We seldom breathe as deeply as we can. By a forced inspiration the lung is able to take in 100 cubic inches more. These extra 100 cubic inches are called the "complemental" air. The amount of air which one is able to breathe from the deepest expiration possible to the deepest inspiration possible is called the "vital capacity." This would then consist of the supplemental air, 100 cubic inches, the tidal air, 30 cubic inches, and the complemental air, 100 cubic inches. In all 230 cubic inches; that is, approximately an even gallon.

Such determinations of the capacity of the lung, of course with the exception of the residual air, may be easily made by means of the spirometer, an instrument found in almost every well-equipped gymnasium.

4.—*The Amount of Air Used.* In the mechanics of respiration there have been considered so far the following topics: 1. The movements of respiration, or those changes by means of which the capacity of the chest is enlarged and contracted, and so the air drawn into it or forced out. 2. The rate of these movements. 3. The capacity of the average lung. A very important topic in the mechanics of breathing still remains to be answered. It is the question

of the amount of air necessary to properly supply the lungs, which includes the rather important subject of ventilation.

Ventilation.

As stated before, we take in at each breath about thirty cubic inches of air; that is, about half a liter. As about fifteen breaths are taken on an average per minute, this makes the amount of air taken into the lungs in that time 450 cubic inches. But the problem of the amount of air is not so simple as that. If each mouthful of air as it is breathed out could at once be snatched away from the mouth and so enable a fresh mouthful to be taken in, 450 cubic inches would suffice. By making careful experiments it has been shown that every mouthful of air that we breathe out is mixed with the outside air and vitiates three times as much additional air, to such an extent as to make it no longer fit for respiration. Or, in other words, every mouthful we breathe becomes mixed with three additional mouthfuls outside, in a way to make the four mouthfuls so resulting perfectly unfit for further respiration. Therefore, the amount of air actually required per minute is not 450 cubic inches, but four times 450 cubic inches, or 1,800 cubic inches per minute. This is just a little over one cubic foot. These figures express rather important results and ought to be kept in mind by persons who have the ventilation of crowded rooms in charge. Fresh air ought to be admitted at the rate of *one cubic foot per minute for each person* in the house. This does not, of course, mean the production of a draft, it being entirely possible to renew the air at this rate even in a fairly crowded room without subjecting any body in it to exposure to a draft.

For proper ventilation an amount of space between 500 and 1,000 cubic feet for each person ought to be available. In some of the better hospitals where the crowding of patients is not permitted, and where the subject of proper ventilation is treated as of the prime importance, the amount of space allowed to each patient is often even more

than this. These figures ought not to be passed over thoughtlessly, but ought to serve as a criterion in judging whether any room in question is really capable of housing one, or two, or three individuals, as the case may be. Students, especially, are sometimes not overly careful in crowding two or three into a small room, the capacity of which would be but little more than that required for a single occupant.

What Vitiates Air?

It was pointed out that in breathing, oxygen is taken from the air and carbon dioxide given to it. But air becomes vitiated and is no longer fit to be breathed, not because too much of the oxygen has been removed, or because too much carbon dioxide is present in it. In an atmosphere in which the amount of oxygen should be materially reduced the blood could still get all of that gas it would need. An atmosphere containing quantities of carbon dioxide very much greater in proportion than that in the air of badly ventilated rooms, would still be perfectly harmless to breathe. Of course if the oxygen supply should be reduced so much as to make it impossible to get enough of that gas, or if there should be so much carbon dioxide in the atmosphere that it would almost entirely replace the oxygen, as it is sometimes in deep wells or in mines, then the carbon dioxide would prove injurious and fatal, but not because it itself is injurious or poisonous, but simply because it has displaced the necessary oxygen.

The thing that makes air which has been breathed once no longer fit for respiration is the fact that such expired air contains organic impurities which have been breathed out from the lungs. It is impossible to determine just what these impurities are, but they are probably volatile substances of a poisonous nature, or may actually be particles of decayed lung or other organic tissue. It is this organic admixture that plays havoc in instances of insufficient ventilation. An idea of the large amount of such organic material breathed out may be gained when we remember how frequently the

breath of persons is tainted more or less strongly with objectionable odors, which in many cases are not necessarily due to a careless condition of the teeth, but due to substances either volatile, or to small particles of disintegrated tissue which have emanated from the lungs. Our bodies seem peculiarly susceptible to such eliminated particles, and an atmosphere that has been vitiated even to a small extent with them becomes at once unpleasant to our nostrils, and if in spite of this warning we persist in breathing it, there results finally a dullness, a headache, or a general indisposition which, if continued from day to day, surely and inevitably leads to an undermining of the general health and energies, and may succeed in cutting the life unnaturally short.

There are persons who seem to think that the importance of ventilation as it is urged by persons who have studied that subject is somewhat of a scientific fad, and the day is not yet here when persons who have the ventilation of crowded rooms in charge always appreciate the importance of the duty so assigned to them. In determining the amount of air which ought to be admitted into a room, stoves which consume large quantities of oxygen, or gas jets which use up a certain supply of the same gas, must be taken into consideration, for the consumption of oxygen in a stove may, under certain circumstances, be many times that of a single person. Then, further, as there are always emanating from a heated stove certain poisonous gases, the necessity for a more perfect ventilation than ordinary is at once apparent.

THE CHEMISTRY OF RESPIRATION.

1.—*Composition of Inspired and Expired Air.* The composition of the air which we inspire is about as follows:

Nitrogen	79 per cent.
Oxygen	20 “
Carbon Dioxide	.004 “
Water in amounts depending on the humidity of the atmosphere.	

In addition to these gases there was recently discovered another gas resembling nitrogen in some of its properties, and called "Argon" by its discoverer, but as this gas does not figure in the processes of respiration a consideration of it may be for our purposes omitted.

If now with such inspired air we compare expired air, we find that a number of changes have occurred in the lungs. First, the expired air is warmer, due to its having remained for some time in the warm lung. Second, as a consequence of this increase in temperature it has expanded slightly in volume, so that the expired air seems at first a little larger than inspired air, and for this reason it tends to rise. However, when expired air is reduced to the same temperature and pressure as the inspired air, it is found to be a little less in volume, showing that a part of the air has actually been taken into the body and kept there. Third, expired air contains a much larger amount of moisture. This is especially evident on a cold day when the breath, as we say, becomes visible, due to the condensation of the large amount of moisture in it. So far the changes are merely physical changes. There is, however, fourth, quite a difference in the chemical composition of the two. The expired air has lost five per cent. of oxygen and gained about four per cent. of carbon dioxide, and finally, fifth, the expired air contains traces of volatile organic substances, and possibly particles of disintegrated tissue to which the vitiation of respired air is due.

It requires special chemical experiments to show that five parts of the twenty parts of oxygen have been removed. On the other hand, the addition of the four parts of carbon dioxide to expired air may be easily shown in a very simple experiment. If a person breathe, by means of a glass tube, through a flask or bottle containing lime-water, the carbon dioxide will unite with the lime-water, and a white precipitate will form insoluble in the water which soon settles to the bottom.

The composition of expired air may then be tabulated as follows:

Nitrogen	79 per cent.
Oxygen.....	15 "
Carbon Dioxide.....	4 "
Water in increased amounts.	
Organic substances.	

2.—*The Amount of Oxygen Consumed in One Day and the Amount of Carbon Dioxide Eliminated in the same Period.* As the amount of oxygen which is taken up by the blood while in the lung is five per cent. of the entire air, we are easily able to calculate, knowing the amount we breathe in at each breath and the number of breaths in a given time, just how much oxygen under ordinary pressure we can consume in, say a day. Such calculations give as the daily oxygen consumption twenty to twenty-five cubic feet. The carbon dioxide is a little over four per cent. and in a day amounts to from sixteen to eighteen cubic feet.

To all students who have taken even elementary courses in chemistry, oxygen and carbon dioxide are things of knowledge. For the sake of persons who have had no training in chemistry it may be in place here to refer briefly to the nature of these two substances.

Oxygen is a gas which forms about a fifth of the ordinary atmosphere, and is that element of the atmosphere which makes burning possible. It is odorless, tasteless, colorless, and so not easily perceived by the senses, yet forming an integral part of the very atmosphere in which we move, and chemically familiar to everybody as the element in the atmosphere which as the draft we lead into stoves and lamps to make combustion possible, it needs no further explanation. Pure oxygen very materially increases the energy of combustion, and in an atmosphere of pure oxygen even such an apparently incombustible thing as a steel wire may be made to burn easily. In the air, however, the oxygen is very much diluted with the inert gas called nitrogen which serves, therefore, in this process of respiration as a mere diluting agent and plays no active role itself.

Carbon dioxide (CO_2) is the gas which results when carbon, or things which contain carbon, such as wood or coal, are burned. It is colorless, and in diluted amounts tasteless and odorless, and so not readily perceived when mixed with the gases of the atmosphere. In a pure form carbon dioxide is familiar as the gas which rises from a freshly-drawn glass of soda-water, the soda fountains being charged and the pressure in them produced by this gas. It is the gas which causes the effervescence when vessels containing any of the so-called "sparkling liquids," such as pop or champagne, are opened.

THE PHENOMENA OF EXTERNAL RESPIRATION.

1.—*The Supply of Oxygen.* Possibly the best way to arrive at a proper understanding of the exact way in which the gaseous interchange in the lungs is accomplished is to get a clear picture of the actual condition of things in that organ. In the first place, in the alveoli is fresh air, brought there by the movements of respiration. In the walls of these alveoli lie the pulmonary capillaries, into which the venous blood coming from the right side of the heart enters. This venous blood in the capillaries is separated from the air in the alveoli by the membranes which form the walls of the capillaries and the linings of the alveoli. Thus there seems to be at first a difficulty in having the air and the blood put in direct contact. Experiments, however, show that a moist membrane which may separate a liquid from a gas may be for all practical purposes disregarded. Thus, if a glass vessel be taken, filled with a certain liquid and a moist membrane stretched carefully over it, and then the vessel be put into an atmosphere of a certain gas, the result will be much the same as if that membrane had been left entirely off, the only difference being that the presence of the membrane slightly retards the rapidity of the gaseous interchange. Thus this apparent difficulty at once disappears and we may therefore imagine the venous blood of the capillaries and the air in the alveoli in immediate contact.

The next question that suggests itself is the exact manner in which the gases of the air enter the blood, and how those of the blood enter the air. In order to understand this it is desirable to turn aside a little and explain somewhat in detail one of the most familiar laws of the physical laboratory, the law which governs the absorption of gases by liquids.

DALTON'S LAW OF THE ABSORPTION OF GASES BY LIQUIDS.

When in any experiment a liquid and a gas are brought together the liquid will at once absorb or dissolve in itself some of this gas, the amount so dissolved depending on the pressure which that gas exerts on the liquid, and varying directly with that pressure. This is not a physiological phenomenon but a general physical law, and applies to all liquids and gases. It was named after the physicist who first carefully proved and formulated the law, and called "Dalton's Law of the Absorption of Gases." This law of the absorption of gases announces the observed fact that the amount of gas which any liquid absorbs depends on the pressure which that gas exerts on the liquid and varies directly with it; that is, if the pressure is doubled the amount of gas so dissolved is doubled; if the pressure is reduced to one-half the amount of gas dissolved is reduced one-half.

There are many familiar illustrations of this law. For instance, in the manufacture of the familiar soda-water it is deemed desirable to have ordinary water absorb very large quantities of carbon dioxide. Under ordinary pressure water absorbs but little carbon dioxide, but to remedy this, the water to be made into soda-water is subjected in a proper system of tanks to a very great pressure of the carbon dioxide gas, and in conformity to Dalton's law the water absorbs increased quantities of that gas. The heavier the pressure in such a charged soda-fountain, the more gas will the water absorb. The same thing is illustrated in the bottling of mineral waters. Here the ordinary water is subjected to a high pressure of carbon dioxide gas, too, and under this high pressure the mineral water dissolves into it-

self increased quantities, and in that condition is forced into bottles which are then tightly sealed, in order to retain the gas at the original pressure. A bottle of mineral water that had been filled from a tank subjected to a carbon dioxide pressure twice as great as that of a second tank would have twice as much carbon dioxide gas in it as a similar bottle filled from the second tank.

The water of our wells and streams is, of course, in contact with the air, and the air presses on it with a pressure equal to fifteen pounds to the square inch. In conformity to the law just given certain and definite amounts of air are dissolved or absorbed by the water. Thus the oxygen which is absorbed in ordinary river water and which serves for the respiration of fishes is accounted for in this way. Dalton's law might be stated in another way which may help to make this matter clearer. Liquids absorb gases until the pressure of the gas dissolved in the liquid is just the same as the pressure of that gas above the liquid. A few illustrations may prove helpful. If, in the case of an ordinary engine boiler a valve be opened in the lower part of the boiler where the water is, the water is forced out with the same pressure as the steam would be forced out from the upper part of the boiler. That is to say, the pressure in the water of the boiler is the same as the pressure of the steam above that water. Or, to illustrate further, in a bottle not quite filled with some heavily charged mineral water there is a certain amount of gas above the liquid. If the stopper from such a bottle should be removed not only would the gas above the liquid be forced out, but the gas dissolved in the liquid would try to relieve itself of the pressure to which it has been subjected, and so flow out of the bottle, frequently carrying bits of the liquid along with it as a froth or foam. As soon as a glass of heavily charged soda-water is drawn and placed on the table to be served, the (CO_2) gas which was dissolved in the water, now being relieved of the pressure of the gas above it, leaves the water and causes the familiar froth, or, as it is called, the effervescence of that

liquid. This loss of gas in all these cases would continue until finally the pressure of the gas in the liquid itself would sink as low as the pressure of that gas in the atmosphere above the liquid, when things would come to a standstill.

The phenomenon of boiling is a still further illustration of this same fact. As the water becomes gradually more and more heated the pressure of steam in the liquid rises correspondingly, until finally a point is reached at which the pressure of the steam in the liquid is a little greater than the pressure of the atmosphere above the liquid. As a result of this the water is thrown upward to allow the steam to escape. This throwing up of the water is, of course, the familiar boiling of the liquids. For this reason we ought to expect that water would boil more quickly the lower the atmospheric pressure. Such is, of course, the case, and water will boil on high mountainous altitudes at very much reduced temperatures. Finally, it may not be altogether out of place to call renewed attention to the fact that such a gas absorbed in or dissolved by a liquid is not held in that liquid in the form of bubbles, but is thoroughly dissolved in it and to the eye invisible. Thus, a bottle of heavily charged mineral water will appear without a bubble in it as long as it remains corked, and yet at the moment of opening, innumerable bubbles will at once form throughout the liquid, sometimes with such rapidity as to cause the whole liquid to froth.

With this little side excursion into the realm of physics, let us turn again to the condition of things in the lungs and see the application there of Dalton's law.

A difficulty at once confronts us. The air is not a single gas. It is made up of at least three gases. It contains about four-fifths nitrogen, one-fifth oxygen, and then traces of CO_2 . The experiments of the physicist again help us out here, for in all cases where a liquid is subjected to a mixture of gases each gas acts independently of all the others; that is, the amount of one gas which will be absorbed by a liquid is not in any way influenced by the

presence of any other gases. We have in every case to do only with the pressure of the one gas in question. Now, one-fifth of the atmosphere is oxygen, four-fifths nitrogen, disregarding for the moment the other ingredients. As the pressure of the atmosphere is fifteen pounds to the square inch, a fifth of that is due to oxygen; that is, the pressure of oxygen to the square inch is three pounds, while the pressure of the nitrogen, the remaining four-fifths of the atmosphere, is of course four-fifths of fifteen pounds, or twelve pounds. In studying the action of the oxygen in the lung, we need only to take into account the fact that the oxygen presses on the blood in the capillaries with a pressure equal to three pounds to the square inch, and we may, without fear of any complications, entirely disregard the presence of the other gases. For if the blood should be put into a closed vessel and all the nitrogen of the air in that vessel be removed chemically, no difference would result. In conformity with the law of Dalton, oxygen will be absorbed by the plasma until the pressure of the oxygen in the plasma becomes the same as the pressure of oxygen above it; that is, three pounds; and the nitrogen will be absorbed by the plasma until the pressure of nitrogen in it will be equal to the pressure of nitrogen immediately above it.

So far there would be not one iota of difference between what happens to the venous blood in the lung and what happens to the water in a river. Both subjected to the same atmosphere would dissolve the same proportion of oxygen and nitrogen. Animals which have colorless blood only, for instance, the oyster or the crayfish, get their supply of oxygen from the amount of this gas which the water of their blood will dissolve. As every one knows, however, ordinary water does not dissolve very much oxygen, and fishes which are put in an aquarium must have the water renewed at very frequent intervals, as the oxygen supply of the water is rapidly exhausted. For this reason animals that can get no other oxygen except that carried

by the liquid of the blood are necessarily cold-blooded, and frequently very sluggish, much like a fire which, devoid of a good draft, would have to burn slowly and smoulder. But in the case of the blood of all higher animals a new factor is added. This new factor is the hæmoglobin contained in the red corpuscles. This hæmoglobin has the chemical property of combining with oxygen whenever the pressure of the oxygen is a *half pound* or more, and of giving up the oxygen just as soon as the pressure of oxygen surrounding it sinks *below a half pound*. This property of hæmoglobin is by no means a unique one. There are many chemicals which, under high pressure, will form combinations with other substances, and at lower pressure will again disunite. We have here to do not with a mysterious physiological problem, but with a simple every-day chemical fact.

THE ROLE OF THE RED CORPUSCLES.

Let us now see just what role the red corpuscle with its hæmoglobin plays in the pulmonary capillaries. In a way described above the oxygen is absorbed by the plasma and the oxygen pressure in the same will at once begin to rise. When, however, this pressure in the plasma rises above a half pound the hæmoglobin will at once seize the oxygen absorbed in the plasma and unite chemically with it. This oxygen so taken out of the plasma is, of course, replaced at once by fresh oxygen which streams in from the outside. As the pressure of the oxygen in the air is three pounds to the square inch, it will continue to stream into the plasma until the pressure there will be three pounds. But before the pressure reaches three pounds, in fact, just as soon as it passes the half-pound limit, the hæmoglobin in the red corpuscles will pick out the oxygen from the plasma, unite chemically with it, and so prevent the pressure in the plasma from reaching three pounds. This will go on until finally all of the hæmoglobin has united with oxygen; that is, until all of the hæmoglobin has been changed into oxyhæmoglobin. After this point is reached

the oxygen will continue to stream into the plasma until the pressure in the plasma reaches three pounds, and then everything will come to a standstill. Of course at this juncture the blood is pushed onward into the pulmonary veins and is as arterial blood sent back to the left side of the heart, to be, of course, in the lung replaced by fresh venous blood from the pulmonary arteries.

By way of summary the condition of things in this arterial blood as it leaves the lungs is re-stated. The plasma of the arterial blood has oxygen dissolved in it to a pressure of three pounds to the square inch, or at least not very far from that. All the hæmoglobin has been changed into oxyhæmoglobin, and as this oxyhæmoglobin is in the plasma surrounded by an oxygen pressure of more than half a pound it does not disunite with its oxygen. In this condition of things the blood is sent out through the arteries over the entire body and finally reaches the capillaries in the tissues. This is the seat of the internal respiration.

THE PHENOMENA OF INTERNAL RESPIRATION.

1.—*The Oxygen Supply.* In order here, also, to more thoroughly understand just what takes place in this gaseous interchange, let us picture the exact condition of things in the tissues. The arterial blood, as described, is in the tissue capillaries. Just outside of the capillaries lies the lymph which bathes the tissues, and in which lie the live cells of the body, the units for which the nourishment of the blood and the oxygen which it carries are intended. These cells immersed in the lymph have a great avidity for oxygen, and use it up as fast as it is carried to them. Stating this in a more scientific way, there is in the lymph, bathing healthy tissues, never much free oxygen, and of course there can then be no oxygen pressure. We have the lymph with no oxygen pressure in it, separated from the plasma of the blood which has a three-pound pressure, by a thin capillary wall. It was pointed out in discussing

external respiration that the presence of such a membrane does not in any way hinder gaseous interchange, and so we may again imagine the plasma in the capillaries in immediate contact with the lymph bathing the tissues. As there is a three-pound pressure in the plasma, and no pressure in the lymph, the oxygen will stream from the plasma into the lymph, just as in opening a bottle of mineral-water where the pressure of the gas in the bottle is much greater than the pressure of that gas on the outside of the bottle, the gas will stream out into the air surrounding the bottle. This streaming of oxygen out of the plasma will continue, until finally the oxygen pressure of the plasma sinks to a *half pound*.

It will be noticed that up to this point the red corpuscles have taken no part at all in the process of the gaseous interchange, but as soon as the oxygen pressure in the plasma sinks to or below a half pound the hæmoglobin is no longer able to remain united with the oxygen, but disassociates. The oxygen so liberated from the oxyhæmoglobin flows into the plasma with which it is surrounded, and from the plasma in turn the oxygen streams into the lymph. This will continue until finally all of oxyhæmoglobin has been disunited, and until almost all the oxygen from the plasma has streamed into the lymph. The oxygen does not accumulate in the lymph, for in the tissues this gas is used up almost as fast as it is brought, and so the oxygen pressure in the lymph, in spite of the amount of gas carried to it, remains practically nothing. The fact that the oxygen does not accumulate but is used up as fast as it is brought explains why it is impossible, even for a very short interval of time, to be deprived of air. It takes but a minute or more of a loss of air to induce the fatal effects of suffocation. About the instant when all the oxygen has been taken out of the blood, this is pushed into the veins and sent back to the heart for a fresh supply.

Here, also, by way of summary, the condition of things in the venous blood as it leaves the tissues is re-stated.

The oxygen pressure in the plasma is very low, less than a half pound. For this reason all of the oxyhæmoglobin has been disassociated and the hæmoglobin only is left. Thus it will be seen that the reason why the blood does not give off any of its oxygen until it reaches the tissues is, that all through the arteries the pressure of the oxygen in the plasma remains constant, but sinks below the critical half pound limit in the capillaries only. In the chapter on Blood it was stated that by far the larger amount of oxygen was carried by the corpuscles and a relatively small amount only by the plasma. The proportion is given by some physiologists as ten to one, but while this is true, it will be noticed from the preceding that the plasma and the oxygen dissolved in it, play a most important role in the process of respiration.

2.—*The Elimination of the Carbon Dioxide.* But the preceding is only half of the story. In the process of respiration not only is oxygen taken up in the lungs and carried to the tissues, but carbon dioxide is picked up in the tissues and eliminated from the lung. There now remains a more detailed description of the actual manner in which this carbon dioxide is picked up in the capillaries and finally thrown out in the lungs.

Carbon dioxide is produced when any tissue in the body is in action. It is the result of activity of the brain no less, probably, than that of the muscle, but on account of the difficulty of observation, the finer details as to the sources of the carbon dioxide have been worked out for the muscles.

In the chapter on the nutrition of the muscle it was pointed out that the food brought by the plasma and the oxygen brought by the blood were built up into living muscle. It is important, therefore, to bear in mind that as far as we now know the oxygen carried to the muscles is not used in burning them, as is so frequently stated, but is used in building them up. Consequently the carbon dioxide does not arise as the immediate product of combustion due to the arrival of the oxygen in the muscles. In the case

of the tissues there is no analogy with the stove. In the stove the fuel and the entering oxygen at once combine, combustion occurs, and carbon dioxide is the result. But in the muscle the food and the oxygen are not at once burned, but are in a way, entirely unknown to us, built into living tissue, much as in the manufacture of gunpowder all the various elements are built up without any combustion taking place, until later, when it is purposely ignited. Upon the ignition of the gunpowder it at once breaks up into a number of burned products, not the least one of which is, by the way here, carbon dioxide. The carbon dioxide in the muscles is due to a disintegration of parts of the muscle substance itself. Thus, the amount of carbon dioxide formed in the muscles will vary directly with the amount of muscular work done in the same way as the amount of smoke in battle will vary directly with the number of shots fired.

To show that carbon dioxide may be formed in a muscle when there is no oxygen present, the following experiment will suffice: If a living muscle, say from a frog, be put in a closed case and all the oxygen withdrawn it will, when properly stimulated, contract as usual, and the production of CO_2 follows. In fact, the absence of even traces of oxygen does not seriously affect the muscle for a while, but it keeps on contracting for some time and finally becomes exhausted because its reserve material, not being replenished, is gradually used up. If the CO_2 in the muscle were the result of the direct burning of the oxygen as soon as it enters the muscle, such an experiment with such results would be impossible.

As all living cells are continually at work, if not in giving rise to motion at least in producing heat and in keeping up the bodily temperature, so there is going on continually in our tissues a production of CO_2 . This gas will at once be absorbed by the surrounding lymph in conformity with the law of Dalton. Thus there will come to be in the lymph quite a little CO_2 pressure. In the blood

of the capillaries there is no CO_2 , as the arterial blood just coming from the lungs has practically no CO_2 in it (the air itself having practically none), so in further conformity with Dalton's law the CO_2 will stream into the plasma of the blood, the walls of the capillaries being entirely disregarded. But, as everyone knows, ordinary water (and plasma is mainly water) cannot absorb very much CO_2 at ordinary pressures. When we do want the water to absorb larger quantities, as in the manufacture of soda-water, such water must be subjected to very high gas pressures. The difficult problem therefore presents itself of explaining how the large amounts of CO_2 which are breathed out at each breath are really carried by the blood. In the first place, the corpuscles of the blood do not carry CO_2 . Blood with the corpuscles left in it carries a little more CO_2 than when the corpuscles are taken out, but this is due to the fact that the corpuscles themselves are soaked with plasma, and the plasma, like any liquid, will absorb certain amounts of CO_2 . We must, therefore, look to the plasma itself as the carrying agent of this gas. And yet by experiment it can be conclusively shown that we breathe out much more CO_2 at each breath than could be absorbed by the plasma in that time. In short, while some of the CO_2 is absorbed by the plasma, some of it must be held in chemical combination. Now just what this chemical combination is, physiologists can not yet determine. It seems, however, highly probable that as the blood is normally alkaline, much of the CO_2 in the capillaries of the tissue unites with the alkaline substances of the blood and forms carbonates. To even the most elementary student in chemistry the following explanation, though given unfortunately in technical, chemical terms, will seem very clear: There are contained in venous blood certain quantities of ($\text{Na}_2 \text{CO}_3$) sodium carbonate. When a liquid containing $\text{Na}_2 \text{CO}_3$ has added to it CO_2 gas, it forms a new combination with this gas, and there results Na H CO_3 , sodium bicarbonate. This Na H CO_3 is possibly more familiar to us as ordinary baking-

soda. As this substance is very soluble in water, and consequently soluble in blood plasma, large quantities of it could be easily carried in solution.

By way of summary what has occurred in the capillaries of the tissue may be re-stated thus: First, the CO_2 has resulted from an actual breaking down of the living tissue. Second, from the tissue it has been absorbed by the lymph which bathes the tissues. Third, from the lymph it streams into the blood plasma. Here a certain quantity of it is carried, merely absorbed or dissolved in it. Fourth, in the plasma a larger quantity of the CO_2 enters into chemical combination with some of the alkaline substances, possibly $\text{Na}_2 \text{CO}_3$, (sodium carbonate,) and forms Na H CO_3 (sodium bicarbonate). This sodium bicarbonate is easily soluble in the plasma, and so in solution is carried lungward in the venous stream.

3.—*The Elimination of CO_2 in the Lungs.* The final scene in this drama of the respiration is, of course, the elimination of this CO_2 from the blood into the lungs. When the venous blood reaches the pulmonary capillaries the CO_2 dissolved in the plasma of the blood at once begins to pass out of the blood into the air, since the pressure of the CO_2 in the air is practically nothing. This streaming out of the CO_2 is, therefore, in regular obedience to the law of Dalton. In this way all the CO_2 merely dissolved in the plasma is finally eliminated. If venous blood were put under the receiver of an air pump and the air above it then exhausted, it would be possible to pump out of the blood practically all of the CO_2 absorbed in it. This portion of the gas then presents no difficulty. It streams out into the lung for the same reason that the bubbles of gas stream out of a bottle of mineral-water when that mineral-water comes in contact with the air. But the difficulty presents itself when we try to explain in what manner the CO_2 , which is chemically combined in the sodium salt, is liberated.

It was stated that ordinary Na H CO_3 is the familiar baking-soda. Baking-soda is used to get the CO_2 gas which is liberated from it when sour milk, or for that matter any acid is poured over it. Everybody is familiar with the fact that if baking-soda be taken and anything sour be added to it, it begins to froth and bubble, and large quantities of CO_2 gas stream out. This is exhibited especially well in the common Seidlitz powder. Here Na H CO_3 and some acid (tartaric, etc.) are mixed together, as a result of which the liquid begins to effervesce very strongly. The addition of some acid to the soda has liberated large quantities of CO_2 gas. Common soda-water (which is but water charged heavily with CO_2) derives its name from the fact that formerly this CO_2 gas was derived from ordinary soda by pouring acids over it. Now it is highly probable that the chemical substance in venous blood carrying the CO_2 in combination, is soda, and to liberate the CO_2 so contained some acid must be present. The acid in the case of the lung is oxyhæmoglobin. While hæmoglobin itself is very faintly acid, oxyhæmoglobin is much more markedly acid. Although this oxyhæmoglobin is not acid enough to appear sour to the taste, it is acid enough to act upon the soda dissolved in the plasma and liberate the CO_2 . It is at once apparent that this oxyhæmoglobin, being formed in the lungs, was not present in venous blood. Consequently there was no liberation of the CO_2 in the veins, but arrived at the capillaries of the lungs the hæmoglobin becomes converted into oxyhæmoglobin, which, acid in its nature, at once reacts upon the soda in the plasma and liberates from this the CO_2 , which then streams out into the lungs.

Thus it will be seen that the CO_2 is carried in two ways; one part of it dissolved in the plasma, which when it arrives at the lungs passes from the plasma into the air of the alveoli in obedience to the general law of gases; the other part united chemically with substances, sodium carbonate ($\text{Na}_2 \text{CO}_3$) in venous blood to form sodium bicar-

bonate (Na H CO_3), and so dissolved and carried to the lung, where it is liberated by the acid action of the oxyhæmoglobin. It will thus be seen that even the apparently simple phenomena of the gaseous interchanges in the blood, in lungs and capillaries are carried on in strict obedience to known physical and chemical laws and arranged with a nicety which is certainly striking.

So far nothing has been said of the nitrogen of the atmosphere. This gas seems to play no part whatever in the respiration of the body. It is, of course, carried by the blood, just as any other gas, but is not used up by the tissues, and so serves only to help maintain the pressure of internal liquids against the air.

THE INNERVATION OF THE RESPIRATORY SYSTEM.

The nerves which are immediately concerned in the movements of respiration are the motor nerves, going to the intercostal muscles and to the diaphragm, and for forced expirations to the muscles of the abdominal wall. All these motor nerves come from the spinal cord, but take their origin further up in the medulla. Hence, cutting the upper end of the spinal cord at once destroys the power to breathe, because it cuts through the path of these motor nerves.

1.—*The Respiratory Center.* These nerves, however, are but the mere avenues along which the impulses to breathe are carried. The impulses themselves originate in the respiratory center, which lies in the medulla just at the end of the calamus scriptorius in the fourth ventricle. (See Brain.) It seems to be a paired center, for when the medulla is cut through the middle line the breathing on each side continues, but an injury to the center itself at once stops breathing. As we usually think an animal is dead as soon as it stops breathing, this point has been called the "vital point." A rather horrible example of an injury to this center is the execution by hanging. In this form of taking life the odontoid process of the axis is pulled out of

its accustomed place by the drop of the body and goes crushing through the medulla. As the respiratory center lies just at this point it is destroyed, and an immediate paralysis of all the muscles of respiration ensues. In consequence of this the criminal dies by suffocation, not being able to get more air. Such a displacement of the neck is called "breaking of the neck." It is tolerably easy to locate this point by introducing sharp-pointed needles into the medulla. A point is soon found which, upon being pierced results at once in a respiratory paralysis, and the position of this point in the floor of the fourth ventricle has just been noted. We must look to this center, therefore, as the source of our respiratory impulses.

The question at once arises, what causes this center to send out impulses along the motor nerves just mentioned? A few simple experiments serve to materially clarify this. If an individual breathes very rapidly and deeply, and so gets into his lungs, and consequently into his blood, increased amounts of oxygen, the center becomes quiescent, and for a little while there is no tendency or temptation to breathe. This might seem to show that it is the absence of sufficient oxygen which normally stimulates the center, for as soon as the blood is richly supplied with oxygen by taking repeated deep breaths, the center becomes inactive. On the other hand, if the supply of air be cut off and the blood in the body becomes strongly venous, the center becomes more and more irritable, sends out stronger and stronger impulses to breathe, until finally the impulses become so strong and scattered as to produce convulsions. In such venous blood there is still a little oxygen, but much carbon dioxide, and the opinion has been advanced that it is not so much the lack of oxygen as it is the presence of carbon dioxide that stimulates the center. Other physiologists, to reconcile both views, combine the two notions and state that the absence of oxygen, as well as the presence of carbon dioxide, serve to irritate and stimulate the center to action. It seems, however, difficult to conceive

how a thing which is absent may serve as a positive stimulus. This savors just a little of a mental absurdity. It is perfectly conceivable how the presence of the carbon dioxide in blood might stimulate the center, but experiments have been made by passing different kinds of blood heavily charged with carbon dioxide through the center, and yet the center has failed to be materially stimulated by these large quantities of that gas. Of late, therefore, physiologists have looked elsewhere for the substance in question.

Quite a suggestive experiment was made when blood which had just passed through a severely-exercised muscle was then injected into the arteries which traverse the respiratory center. A very violent stimulation was at once the result. This would seem to indicate that when tissues such as the muscle are hard at work there is a production of waste products of some kind which act as a powerful irritant to this center. This irritating waste product may possibly be eliminated in the lungs, or possibly destroyed when the blood becomes arterial, either case explaining why increased breathing will serve to lessen the stimulating effect of this substance. If, for instance, the blood does not succeed in passing to the lungs rapidly enough, this irritating waste product accumulates in the blood, and so stimulates the center to more and more activity. If, on the other hand, by the process of breathing this substance is eliminated, either through the lung or destroyed in the blood as soon as it becomes arterial, we can understand why when such blood passes through the center the center remains quiet and inactive. This will explain why there are no respiratory movements before birth, for at this time the blood stream is richly supplied with oxygen from the maternal wall. This waste product is given no chance to accumulate in the blood, but by the oxygen from the placenta it is continually removed. On account of this the center is not at all stimulated and so remains perfectly dormant, sending out not a single impulse to breathe. However, at the moment of birth, when the circulation with the placenta is cut

off, and the supply of oxygen becomes short and this waste product, therefore, accumulates, the center becomes at once irritated by it to a greater and greater extent, until finally the movements of respiration are ushered in.

That condition in which the blood is so richly supplied with oxygen that there is no tendency to breathe, is called *apnœ*. The condition in which the center is normally stimulated is called *eupnœ*, while finally that condition in which there is not an adequate supply of oxygen, and which leads to the phenomena of suffocation and to the convulsions accompanying the same is called *dyspnœ*. From these definitions it will be seen that the condition of respiration before birth is that of *apnœ*. But it not infrequently happens that even before birth the circulation with the placenta is interrupted, the oxygen supply of the foetus is cut off, and so *dyspnœ* results, which may lead to real active respiratory movements.

As the tissues are always in action and as this irritating substance, therefore, must continually be forming, we are forced to believe that this center must be continually irritated by this substance. The question then at once arises, why this center which is being constantly and without interruption irritated will give rise to impulses which are periodic. Why would not a continued stimulation of this center produce a tetanus just in the same way as a continued stimulation of the nerve of the muscle would produce a continued tetanic contraction? This is explained by supposing that there is a kind of resistance in this center, and that an impulse does not result until this intrinsic resistance to act is overcome.

This center is, using a rather far-fetched metaphor, a kind of intermittent spring. Such an intermittent spring will discharge its waters periodically in spite of the fact that its supply flows into it at a constant and uniform rate. So in this center. The stimuli from this irritating substance normally found in venous blood, and possibly, as was stated, a waste product of the active tissues, keep flowing in, ac-

cumulating their force, so to speak, until finally such stimuli give rise to a respiratory impulse. Or, to take another illustration. We may imagine a box, the bottom of which is held in place by a spring. If, now, water be poured into this box and the spring have an appreciable amount of strength, it will not at once drop, but the water will accumulate in the box, rise to a higher and higher level, until finally the weight of the water in the box will become greater than the strength of the spring supporting the bottom, when the bottom will drop out, and the water flow out with one gush. As soon as the vessel has thus emptied itself the spring again pushes the bottom in place, and the process repeats itself. Here, too, we see how a source that is constant is changed into an effect which is periodical.

2.—*Nervous Control of the Respiratory Center.* But this center reflexly stimulated by the blood which traverses it, may be controlled within certain limits by nerves going to it.

(1) Those nerves from the brain which are under the control of the will reach it, and every one is familiar with the fact that within a wide range he is able to control his movements of respiration, but that as soon as this range is passed the movements go on independently of the will.

(2) Sensory nerves of the body which, when violently stimulated, affect this center. Thus, excessive pain in almost any region of the body at once influences the rate of breathing.

(3) The most important influences reaching this center come from the sensory nerves of the lung itself. These sensory nerves run in the large vagus trunk.

That these sensory nerves play a most important role in controlling the center, may be understood from the following experiment: If the vagus on one side be cut, no marked effect follows; but cutting both vagi, there at once results a very much slowed breathing. The number of breaths may sink to one-fourth, or even one-sixth of the normal. The

individual breaths are, however, deeper. If, now, the central ends of the vagi, that is those connected with the brain, be stimulated with electrical stimuli, the number of breaths begins to rise to the normal: Here is, of course, an evident control of the respiratory movements. If these vagi are then excessively stimulated there ensues sometimes a relaxation of the respiratory muscles, that is a passive expiration; at other times a standstill of the chest and lungs in the position of an inspiration, in which the respiratory muscles are in a state of tetanic contraction. Here we have then apparently a double effect; sometimes relaxation, sometimes greater contraction. This double effect shows that the vagi have two kinds of nerve fibres in them going from the lungs to the center. First, those that stimulate the center to greater respiratory exertion; and, secondly, those that tend to inhibit the center.

The rather interesting question now presents itself: Under what circumstances does each of the nerves act? The solution of this question is probably found in the following experiment: If the lung of an animal whose chest has just been opened, be forcibly distended by pressing air into it, there is at once developed a strong desire on the part of the animal to breathe out. An expiration is induced. If, on the other hand, the air be sucked out of the lung and the lung so tend to collapse, there at once follows a strong inclination for an inspiration. In other words, when the lung expands the center is inhibited, breathing movements stop, and the muscles relax. But the lung expands in an inspiration, consequently an inspiration induces an expiration. But in an expiration the lung is compressed, and this compression of the lung stimulates the center to act more energetically; that is, the center tends to breathe, but actively breathing means to inspire. Thus the expiration serves to induce an inspiration. We find, then, in these nerves a kind of self-regulating arrangement which stated again is as follows: When the center sends an impulse to the muscles of respiration and the chest is thus

enlarged, the lung is correspondingly expanded. But such an expansion of the lung at once affects those sensory nerves in it which, when stimulated, inhibit the center; that is, cause it to stop. So, as the inspiration proceeds and the lungs expand more and more these nerves are more and more stimulated, the center is more and more inhibited, and is finally brought to a standstill. As soon as this happens the muscles of respiration relax and the chest collapses of its own accord; that is, a passive expiration follows. But in this passive expiration the lung is compressed, and this compression of the lung affects the second pair of sensory fibres which serve to stimulate the center to greater activity. Thus, as the lungs collapse more and more, these stimuli become stronger and stronger, and so finally arouse the center to a renewed contraction.

(4) In addition to these two sensory nerves, which in the manner just indicated so materially influence the activity of this center, there is one additional nerve which exercises a marked effect. This is the nerve which goes to the larynx. This nerve when stimulated, strongly inhibits the center, and so tends to make an inspiration impossible. As this nerve is no doubt stimulated in the varying acts of swallowing, singing, talking, and so on, there seems some reason for this arrangement. Thus, in the act of swallowing the center is inhibited, and so the possibility of choking is materially reduced, while in the act of talking or singing stimulation of this nerve tends to check the rate of breathing, a circumstance which materially helps to sustain the voice.

When all these rather remarkable niceties in the nervous control of the movements of respiration are stated, there yet remains much that requires further investigation, and it is possible that the researches of the immediate future may materially modify and clarify our present knowledge of this subject.

Those modified forms of breathing familiar to us all as sneezing or coughing, may be so easily investigated by each student for himself that a further description of them is here deemed unnecessary.

CHAPTER X.

THE LARYNX AND THE PRODUCTION OF ARTICULATE SPEECH.

The only property which man possesses par excellence to the exclusion of all other animals is that of articulate speech. The voice is something which belongs to the human larynx alone. Many of the lower animals are able to produce characteristic sounds, and these sounds sometimes, as in the case of birds, may extend through quite a wide scale and be of a complicated character; but it goes without question to say that they possess none of the real peculiarities of articulate speech. The human voice consists of sounds which are produced by the vibrations of two elastic bands called the vocal cords placed in the voice-box. This voice-box, or larynx, is really no more than a dilatation of the upper portion of the trachea so arranged with a series of cartilage as to enable the air driven through it to set the vocal cords in vibration. The consideration of the voice immediately after the subject of respiration, is based upon its somewhat secondary connection with the trachea and lungs. Fundamentally the physiology of respiration and that of articulate speech have nothing in common.

The vocal cords vibrating alone would produce but feeble sounds quite different from the ordinary sounds of the voice. The vibrations of the vocal cords are, therefore, strengthened by resonance cavities, like the vibrations of a violin string are very integrally strengthened by the resonance of the violin frame underneath, or as the note of an organ pipe is very dependent indeed upon the resonance cavity in the long tube of the pipe in question. The resonance cavities for the vocal cords are the larynx itself, the

throat, the mouth, and in the production of some sounds even the nose. By changing the relative dimensions of these resonance cavities the quality of the individual sounds of the voice may be much varied, just as the player on the sliding trombone varies his notes by varying the relative lengths of the resonance cavities in his instrument. The pitch of the voice will be dependent upon the length and tension of these vocal cords, just as the pitch of a piano string is dependent upon its length and tension, while the loudness will depend upon the strength with which the vocal cords are made to vibrate.

We have now to consider the anatomical arrangement of the larynx by which the vibration of the cords and the production of the voice is effected.

THE ANATOMY OF THE LARYNX.

The larynx is the expanded upper portion of the trachea. It consists of three main cartilages, the general arrangement of which is about as follows: At the base of the larynx is the cricoid cartilage. This cartilage entirely surrounds the base of the larynx like a ring surrounds a finger. This cricoid cartilage actually resembles in its shape a signet ring, the signet of which is, however, towards the back, and the band of the ring forwards. This band may be felt by pressing the finger hard against the base of the larynx in front. Placed upon the band of this ring, that is, towards the front of the trachea, is the thyroid cartilage. This cartilage really consists of two cartilages which meet in front, leaving a V-shaped slit. The two halves after partially encircling the larynx do not meet behind, as the signet of the cricoid cartilage separates them. This is the largest of the cartilages and is the one we have in mind when we speak of the "Adam's apple." The V-shaped slit in this Adam's apple is readily felt with the finger. The sides of the thyroid cartilage where they join the signet of the cricoid behind are prolonged upwards into two horns, indicated by *C s*, in Fig. 93. Similar horns, although not

quite so large, extend downward a short distance, shown at *C i*, in the same figure. On the signet of the cricoid behind

Fig. 93.—THE CARTILAGES OF THE LARYNX FROM BEHIND.

t, thyroid; *Cs*, *Ci*, superior and inferior horns of thyroid; ****, cricoid cartilage; *†*, arytenoid cartilage; *Pv*, corner to which the posterior end of vocal cord is attached; *Pm*, point of insertion of the muscles which approximate or separate the vocal cords; *co*, cartilage of Santorini.

are placed the two arytenoid cartilages. These arytenoid cartilages are so placed on the cricoid as to permit a good deal of motion. They can be pulled apart, approximated, and even rotated by muscles which reach them. Each arytenoid cartilage is a triangular structure with its base resting on the cricoid. On the top of each arytenoid cartilage is situated a small cartilage known as the cartilage of Santorini. A little forward of this on each side is finally a still smaller cartilage known as the cartilage of Wrisberg. In order to understand the manipulation of the voice-box, however, no special attention need be paid to either the cartilages of Santorini or Wrisberg.

From the inner corner of the base of each arytenoid cartilage, marked *Pv* in the diagram, there extends forward across the larynx to be inserted in front in the thyroid cartilage, an elastic membrane, the true vocal cord. These cords are, however, not separate and distinct strings but

the mucous membrane lining the larynx is reflected over these and so makes the vocal cords really membranes, free only along their inner edge. The analogy of these membranes might be found in a drum, the membrane of which had been slit from one end to the other through its middle. As the forward ends of the vocal cords are inserted in the immovable thyroid cartilage, their length and tension must be varied by the movements of the arytenoid cartilages be-

Fig. 94.—THE INSIDE OF THE VOICE-BOX,

a, a' arytenoid cartilage; *cv*, vocal cord; *t*, thyroid cartilage; *s*, cartilage of Santorini; *cap*, articulation of arytenoid with the cricoid cartilage; *c, c*, cricoid cartilage; *cth*, space between thyroid and cricoid cartilages.

hind. It was pointed out that these cartilages connect with the signet of the cricoid in a very movable joint, and there now remains the description of the muscles by which the desired movements are to be brought about.

THE MANIPULATION OF THE LARYNX.

1.—*The movements which bring the vocal cords into the position found in quiet breathing.* In quiet breathing, when the passage of air through the larynx produces no vibrations, the vocal cords are relaxed and separated, and so

the slit between them, called the glottis, is wide open. This widening of the glottis is produced by two sets of muscles called the crico-arytenoids (posterior and anterior). (The student will find much help in remembering the names of these muscles if he keeps in mind that the name in every case is derived from the two cartilages between which the muscle exerts its pull.) The crico-arytenoid muscles are muscles which are fastened at the outer basal corner of the arytenoid, at the point marked *P m* in the diagram. From this point one runs forward to be inserted on the inner side of the cricoid, the anterior cricoid-arytenoid; one backward to be inserted on the back side of the cricoid, the posterior crico-arytenoid. A moment's reflection will show that the simultaneous contraction of these two muscles will tend to pull the arytenoid cartilage to which they are attached outwards, and as this is true for both arytenoids, they will be pulled apart, and as the vocal cords are attached to these they will also be separated and the glottis opened. To make this perfectly clear imagine a muscle attached at the point *P m*, and inserted immediately below that at the base of the cricoid. When that muscle contracts it is evident that the arytenoid will be pulled out; that is, away from its fellow, and so the glottis opened.

2.—*The movements which bring the vocal cords into a position to vibrate.* In the production of vocal sounds the glottis is very much narrowed. The vocal cords, and consequently the arytenoids to which they are attached, are moved towards each other. This approximation of the arytenoids is brought about by two sets of muscles called transverse and oblique arytenoids. The transverse arytenoids are bands of muscles which run from one arytenoid directly across to the other. The oblique arytenoids run from the lower portion of one arytenoid to the upper portion of the second arytenoid. It is quite obvious that by the contraction of these two sets of muscles, transverse and oblique, the arytenoids will be pulled together, the vocal cords attached to them brought closer together and the glottis nar-

rowed. When, now, the air is driven past these stretched membranous flaps they are set in vibration and the tone arises.

3.—*Movements which bring about the change of the pitch.* Any one familiar with musical instruments is aware that there are two ways in which to heighten the pitch of a string, or in this case a membrane. One method is to increase its tension, as we do by tightening a violin string, the other by shortening the string, a procedure also used on the violin, where, by the placing of the finger, the length of the string is varied to suit the pitch. Both of these methods are used in the larynx.

First, the vocal cords are stretched. This is accomplished by the contraction of muscles which lie towards the front of the larynx, extending from the cricoid band to the thyroid cartilage above it. This is the crico-thyroid muscle, one of which lies on each side of the larynx. When these muscles contract they pull the thyroid cartilage down toward the cricoid. The cricoid band being fastened securely to the upper portion of the trachea, is immovable, and so the only motion possible is the downward one of the thyroid above it. But as the vocal cords are attached in front to the thyroid cartilage they will be pulled down with it and

Fig. 95.—To show the manner of producing changes in the pitch of human voice. (Martin).

For the explanation of figures see text.

will therefore be stretched. Reference to Figure 95 will make this clear. Here *c* is the signet of the cricoid carti-

lage, *d* the band encircling the upper end of the trachea, *l* and *t* parts of the thyroid cartilage, *a* the arytenoid cartilage, *v c* the vocal cords. Now, the crico-thyroid muscles are attached at *d* and inserted near *t*, and when they contract they pull *t* down into the position of *t'*. But this stretches the vocal cords, as the distance from *a* to *t* is shorter than the distance from *a* to *t'*. An apparent paradox appears here. In the position *t'* the vocal cords are actually longer than in the position *t*, and yet in the longer position are used to produce higher pitches. Other things being equal, the longer string will produce a lower note, but the slight increase in length here is much more than compensated by an increase in the tension of it, and so the pitch is raised. It is this crico-thyroid muscle which is most commonly brought into play in the change of the pitch of the voice. To bring the vocal cords, or rather to bring the thyroid cartilage back into its natural position, there is a muscle lying within each vocal cord and extending from its insertion in the arytenoid to its insertion in the thyroid. This muscle, the thyro-arytenoid is, therefore, the direct antagonist of the crico-thyroid.

Second, the pitch of the voice is also changed by shortening the vocal cords. This is accomplished by the crico-arytenoid muscles already referred to in explaining the widening of the glottis. When the anterior crico-arytenoids contract it is evident that the arytenoids will be made to rotate on their vertical axes in such a way that the point *Pm* is drawn inward and forward, but the point *Pv* to which the vocal cords are attached drawn outwards and backwards. A simultaneous contraction of the two anterior crico-arytenoids would result in moving the inner points (*Pv*) together, and if the contraction were strong enough, might put them in contact. As the vocal cords are attached at the inner points they will be brought into contact with each other and so those portions of the vocal cords be prevented from vibrating. In other words, the vibrating portion of each vocal cord is made shorter, and consequently the pitch is

increased. If, for instance, the posterior halves of the vocal cords were touching and so not sounding, the sounding portion would be only half as long as before, and our knowledge of music would make it evident that the pitch would be just an octave higher. For when a violin string is pressed down at this middle point its pitch is raised by one octave. By varying the length along which the vocal cords are thus pressed against each other, that is, by varying the length of the sounding vocal cord, a corresponding range in pitch is effected.

4.—*The range of the human voice.* The range of the human voice is not far from three octaves, although great singers have frequently exceeded this. On account of the much shorter voice-box in children, the pitch of their voices is much higher. In the case of boys there occurs about the time of puberty a somewhat rapid elongation of the vocal cords, referred to in the common expression, the "breaking of the voice." This elongation causes a material deepening of the voice, but as the elongation is not the same for all individuals, so there are differences in pitch which we recognize in designating some as bass singers, others as tenor singers. In the case of girls no such elongation of the vocal cords seems to take place, and so the pitch of a woman's voice remains about an octave higher

Fig. 96.—THE ORDINARY RANGE OF VOICE.

through life. The average range of the human voice for the four usual divisions, bass, tenor, alto and soprano, is indicated in the accompanying diagram.

SPEECH.

Speech is a combination of vocal sounds (vowels), with noises (consonants). Vowels have musical and harmonic properties; consonants are not tones in this sense at all.

The vowels, A, E, I, O, U, and their derivatives are produced by changing the relative dimensions of the resonance cavities connected with the voice-box. As far as the vocal cords are concerned the same vibrations might produce all of the different vowels. Which vowel it shall be is determined by the resonance cavities. Thus, no matter which vowel we sound, the vocal cords act alike if the pitch be the same, and whether it shall be A, E, I, O, U, or any of their derivatives will depend upon the quality or timbre which is given to these vibrations by the sounding cavities. Any one can assure himself of this by sounding A, as in father, and then without any change in the vocal cords change his mouth to the position of O, and then OO. I is, of course, a combination consisting of A, as in father, and E as in feet. The same is true of U, consisting of E, as in feet, and OO as in loose. That the production of the vowels is dependent upon the form of the resonance cavities is a subject which each person interested can so easily verify for himself that further discussion seems unnecessary.

Consonants are sounds which are produced in most instances with little help of the vocal cords, but are brought about by modifications of the manner in which the blast of air is expelled through the mouth. For instance, the current of air may be interrupted near the teeth, as in the consonant T, or by the tip of the tongue, as in the letter D, or by the lips, as in the letter P, or even by the soft palate at the root of the tongue, as in the letter G (in the word go). Some of the consonants are produced by a sudden explosive blast of air, as for instance. D, G, B, K, T, P. Others are continuous, being produced by the rush of air through narrow passages either between the lips, as in F, or the teeth, as in S, or when the approximation is still closer, as in TH. In the case of L the tongue is pressed against the hard

palate and the air allowed to escape on its sides. With some consonants there is an admixture of vocal sounds, as in B, D, G (hard), V and Z. In the production of other consonants the nose is called into play as a resonance cavity, and so arise M, N and NG. In the consonant R there is a vibratory motion, either dental, as is more common in the English language, or guttural, more usual in the German. H, finally, is hardly more than a laryngeal sound, little more than hard breathing.

Whispering differs from true speech in the absence of all vowels. It is, therefore, in a physical sense, a noise only. In whispering, although the glottis is considerably narrowed, the cords are not stretched enough to vibrate, and the air made to rush past them is therefore thrown, not into regular, but into irregular vibrations. Such irregular vibrations as happen to coincide in period with the air in the throat or mouth serve to characterize the vowels, while consonants are produced in the ordinary way.

In the discussion of the voice reference has always been to what is commonly known as the chest voice. It is possible in addition to produce what are called falsetto tones, but the manner in which this is accomplished is not yet satisfactorily known.

CHAPTER XI.

GLANDS AND THE GENERAL PHYSIOLOGY OF SECRETION.

HISTORICAL.

The ancients had practically no knowledge of secretion. They thought that the phlegm from the nose was a discharge from the brain. Their other views were not less mistaken. This misconception lasted until 1660, when Schneider's researches on the olfactory membrane proved its falsity. About this time, too, a number of eminent anatomists appeared, whose researches on the structure of glands materially cleared up the meaning of these organs. The names of many of these noted anatomists are still retained in connection with the terminology of glands. Thus, Glisson (Capsule of Glisson in the liver), Stenson (Duct of Stenson in the salivary glands), Peyer (Patches of Peyer in the intestines), Brunner (Glands of Brunner in the duodenum), and Malpighi (Malpighian corpuscles of kidney). Our anatomical knowledge became finally fairly complete when in 1830 Johann Mueller's large treatise on glands was published.

Thus far, all the work had been of an anatomical nature and the physiological process of secretion remained for some time longer entirely unknown. The view held was that the blood capillaries actually communicated with the ultimate tubules of the ducts of the gland, and that the secretion was a kind of direct separation from the blood, in which the corpuscles did not take part, because the smaller tubules of the duct were too tiny to allow them to pass from the blood. The correct view of the process of secretion, however, soon followed the discovery of the cellular structure of animal tissues by Schwann, and the discovery of

the physical process of osmosis. The influence of the nerves on secretion was then demonstrated in vivisections made by Ludwig in 1851, who by electrically stimulating the cerebral nerve going to the submaxillary of the dog caused a secretion of saliva, which rose to the height in the tube of 200 millimeters of mercury, while the height of the blood in the carotid artery rose to 112 millimeters of mercury only. The action of the sympathetic nerve on secretion and the changes of the vascular supply of glands were in 1858 discovered by Claude Bernard. Finally the microscopist, Heidenhain, made a series of researches on the histological changes in secreting cells, which have demonstrated that the secreting cells themselves are the seat of active chemical changes which form the secretions.

SECRETION.

The term "secretion" is frequently made to apply to a varying number of things. Sometimes all the substances which are given off by the blood are called secretions. This would make the lymph which oozes out of blood capillaries a secretion, and would also make the gases which figure in respiration secretory products. This use of the term secretion is, however, much too wide, for physiologically speaking, lymph and the blood gases do not figure in any way as the product of glands proper. In the second place, the term "secretion" is made to apply to all the discharges of all the various glands. There is no special objection to this application of the term. Other physiologists, however, speak of secretions and excretions, calling "secretions" those products of the glands which are intended for a further use in the body, and apply the term "excretions" to those glandular discharges which are intended for no further use, but are simply to be thrown off. But even these uses of the term are not satisfactory, because it is not always easy to tell whether a certain secretion is directly intended for further use, or is a mere waste product to be eliminated. To do away with such an ambiguity, therefore, the term

secretion is here applied to all the products of all the glands. Before following out in detail, now, what the exact process of secretion is, it is necessary to turn to the anatomy of glands.

1.—*Glands and Their Anatomy.* Here additional ambiguities are at once misleading. There are a number of structures in the body designated as glands which are not true glands in any sense of that term. They were called glands by anatomists who were ignorant of their real nature, and these names given to them in this way still cling to them in spite of our knowledge that they are not glands at all. Just as we call the primitive inhabitants of America Indians without intending to express in any way the misconception that they are residents of the East Indies. Such entirely different structures are the pineal gland of the brain, which instead of being a gland is really but the stump of an optic nerve. Such structures, too, are the lymphatic glands, which are aggregations of white blood corpuscles, and have absolutely nothing to do with secretion in any way.

In addition to the structures just mentioned, which are at the very first glance seen to belong to entirely different tissues, we have several structures which, while they may be the seat of chemical changes in the blood passing through them, yet have no ducts, and do not pour out distinct secretions. They are, therefore, not infrequently called "ductless" glands. Examples of such are the spleen, the thyroid gland and the adrenal glands. Disregarding all these, then, it may be said that a typical gland consists of a basement membrane of connective tissue bearing a surface of secreting cells on one side, and supplied with numerous blood vessels on the other. In addition to these three main elements there are, of course, nerves which in some instances have actually been traced by anatomists into the secreting cells themselves. Finally in the interstices, as in all other tissues, are the lymphatics. It will be seen from this that

a gland is but a surface of secreting cells supported by a basement membrane, richly supplied with blood-vessels underneath the membrane, and subject to the control of nerves.

Fig. 97.—FORMS OF GLANDS. SIMPLE SACCULAR GLAND FROM AMPHIBIAN SKIN. (Flemming.) SIMPLE TUBULAR GLAND FROM HUMAN INTESTINE. (Flemming.) GLAND FORMED OF A SIMPLE DUCT-SYSTEM. (Flemming.) CONSTRUCTION OF A LOBULE OF A COMPOUND RACEMOSE GLAND (*a*, duct; *b*, *b*, branches of duct; *c*, secreting alveoli). PART OF A SMALL RACEMOSE GLAND, SHOWING THE TUBULAR CHARACTER OF THE ALVEOLI. (Flemming.)

A gland, however, spread out as such a flat surface, would take up a very great deal of room in order to secrete the amounts necessary to the body. To save space, therefore, these glandular surfaces become pitted in and folded, and in this manner result the various forms of glands. Examples of the typical surface glands are not wanting. Thus, the peritoneum, the pleura and the pericardium have such

flat surfaces which secrete the serous fluids. Nearly all the other glands, however, are modified. Usually space is saved by pitting in the secreting surface and thus *tubular glands* arise. Sometimes these, instead of being straight and tubular, become rounded and sac-like, in which case such a gland is called a *racemose gland*. When several such tubular or racemose glands have a common duct leading from them, the entire structure is spoken of as a compound gland.

Illustrations of the simple tubular glands may be found in the gastric glands of the stomach, and in the crypts of Lieberkühn. Illustrations of the simple racemose glands occur in the sebaceous or oily glands of the skin. However, most of the larger glands, such as the pancreas and the salivary glands, are of the compound racemose kind. Such a compound racemose gland might be compared to a

Fig. 98.—SECTION OF A RACEMOSE GLAND, SHOWING THE COMMENCEMENT OF A DUCT IN THE SECRETING ALVEOLI. (After Schäfer.)

a, an alveolus; *b*, basement membrane lining the duct *d'*; *c*, connective tissue between the alveoli; *d*, duct; *s*, semilunar reserve cells.

very full bunch of grapes in which the central stalk figures as the single duct, while the individual grapes represent the ultimate sac-like expansions, in which the process of secre-

tion occurs. If, now, between such bunches of grapes we should imagine a very full network of blood-vessels and a supply of nerves, we should have a coarse but possibly a helpful analogy.

2.—*The Process of Secretion.* Such an arrangement of a gland with a basement membrane and blood-vessels naturally suggests the possibility of secretion being a mere case of physical filtration. We know, for instance, that if a liquid containing things in solution be put into a membranous bag, such a liquid by the process of osmosis reaches the outside. There are, however, certain facts which make it at once perfectly plain that the process of secretion is not a process of physical filtration. Quite a number of glands secrete substances which are not found in the blood at all. They secrete substances which they themselves have produced. Thus, for instance, the pepsin of the stomach, or trypsin of the pancreas, and the ptyalin of the salivary glands are not contained in blood at all. Such special products which the glands have themselves produced are called specific elements. In this sense we speak of the hydrochloric acid, rennet, and pepsin of the stomach as the specific elements of that organ. If secretion were a physical filtration, specific elements would be impossible.

But the question then recurs, may not the remaining elements of a secretion be merely filtered through. This question must be answered in the negative for several reasons. *First*, glands secrete at certain times only, while if it were a physical filtration the process ought to go on all the time, for even when a gland is at rest the blood circulates through it freely. *Second*, a certain poison called atropine (of frequent use in the physiological laboratory) destroys the secreting power of a gland at once, but it does not change the blood pressure in the gland at all. Such a poisoning action would be impossible in the case of simple filtering. *Third*, glands may be stimulated to such increased action that the pressure of the secretion may actually exceed the pressure of the blood in the gland; a condition of

things never possible in simple osmosis. *Fourth*, glands may be made to secrete even when they contain no circulating blood. Thus, if the sciatic nerve in an amputated limb of an animal be stimulated the sweat glands may be made to secrete, when it is evident that there is no circulating blood in the severed limb. We are driven, therefore, to the conclusion that secretion is a phenomenon of the living gland cells themselves, and its ultimate nature we understand as little as we do the ultimate nature of muscle activity or nervous impulses. It is a chemical process whose explanation is not yet at hand.

3.—*Histological Changes in Secreting Cells.* On the other hand, while we do not understand the exact nature of the process of secretion, we are able to observe on a gland certain histological changes in rest and in action. Thus, when a gland starts to secrete it at once becomes flushed with blood, due to the enlargement of the arteries traversing it. Such a dilatation has, however, nothing to do with the gland itself, but has been brought about by nerves which run to the arteries direct, and which were stimulated at the same time the gland cells were stimulated. The purpose of such an increase in the supply of blood to a working gland is, of course, very apparent. It is to carry abundant material to the gland, and supply it with sufficient amounts of oxygen to sustain its activities. It differs in no essential way from the condition of things in a working muscle.

But histological changes may be observed in the secreting cells themselves, for a gland that has been actively secreting looks quite different under the microscope from one which has been at rest for some time. If, for instance, two animals as nearly alike as possible be taken, and one of them be starved for a day, and thus the pancreas of that animal be given no occasion to pour out its secretion, and the animal be then killed and the pancreas observed histologically, it may be seen that the gland cells are distended and that their outer portions, that is, the portions next to the lumen of the gland, are filled with granules, while those

portions of the cells next to the basement membrane seem clearer and more protoplasmic. If, now, for comparison with this gland there be examined the pancreas of the second animal, which was plentifully fed eight or ten hours before being killed, quite a different appearance of the secreting cells is at once evident. The cells seem smaller, and the granular layer is almost wholly absent, the whole cell now from basement membrane to lumen appearing clear.

It is not difficult to account for the relative appearances of these two glands. In the working gland which has just been called upon for a copious secretion the granules have been used up; have, in other words, been changed into a part of the secretion of the gland. If, however, a gland which has been copiously secreting, be given opportunity to recuperate, the granules again begin to appear, become

Fig. 99.—PARTS OF GLANDS. (After Langley.)

A, at rest, almost filled with zymogen granules; *B*, after a short period of activity; *C*, after a prolonged secretion. In *A* and *B*, the nuclei are obscured by the granules.

more and more plentiful, and soon occupy almost half of the space of the cell. The condition of things is then this: In the process of secretion the pancreatic cells (which gland is here used as an illustration of glands in general) change these stored-up granules into the secretion, while during the period of apparent rest the gland seems engaged in manufacturing and storing up these granules ready for the next secretion. It will thus be seen that the process of secretion in cells is essentially a process of growth. The secreting cells take proper nourishment from the blood bathing them, and in that way construct within themselves,

possibly out of their own substance, the specific elements in question. Somewhat like a sheep by taking the proper nourishment into its body, and by chemical changes in its tissues, may produce the woolly covering of the skin.

That the specific elements of glands are thus built out of the cells themselves is especially well shown in the case of the oil glands of the skin. In those glands some of the cells may be seen to grow large, then by internal chemical changes their own substance apparently disintegrates into oil, a change which continues until finally the whole cell falls into pieces, and its debris forms the secretion. In other cells the destruction is not complete, but only portions of the cell break up into the secretion in question. In such cases, of course, an individual cell by continuing to grow and continuing to form out of its substance the specific element may remain active for an indefinite time, while in the case of cells where the disintegration is complete, new cells must continually be forming to replace those that break down.

In the case of the pancreas a complete destruction of the cells does not occur, as it does in the case of the oil gland. To take a not very close analogy, the secretion of a gland is not a product made by the cell in the same sense that a table is a product made by a carpenter, but the secretion is a product derived from the cell substance itself, as the table is a product of the oak tree.

In the case of the pancreas these granules are not, however, identical with its specific element. The main specific element of the pancreas is called trypsin, whose marked influence in digestion will be discussed later. But the granules in the pancreas cells are not trypsin. They are some antecedent substance out of which, however, by slight changes trypsin is produced. The granules are called trypsinogen granules; that is, by the etymology of that word, the producers of trypsin.

Several fortunate circumstances arise by this arrangement. Trypsin is soluble and could not easily be stored up in

the gland. It has a digestive action which might lead it to attack the gland itself in which it is stored. Both of these difficulties are avoided by forming the trypsinogen granules. These are, in the first place, solid and can easily be stored. In the second place they do not have the active digestive properties of the trypsin and so exert no digestive action at all. When, then, finally the trypsin is needed all this stored trypsinogen may by slight changes be at once transformed into trypsin and so poured out in large quantities into the intestines. Trypsin is a digestive fluid of rather complex composition and it would be practically impossible for the pancreas to secrete large quantities of this at sudden notice, but by devoting all of its resting period to the production of these trypsinogen granules, storing these up in the outer part of each cell, and then just at the moment when the trypsin is needed changing these trypsinogen granules into the soluble trypsin, sudden and large quantities of trypsin are at once available.

What has been said with reference to the pancreas applies to the mucous glands. Here during rest are produced granules which at the proper occasion are changed into mucus and poured out. These stored granules are called mucinogen granules. While it has been impossible to actually demonstrate a similar condition of things in the gastric gland, there is every reason to believe that here, also, during the resting period of the stomach the peptic cells are storing up granules of pepsinogen. Such granules not being easily dialyzable could be stored in the cell, and not having the active digestive property of regular pepsin, would exert no chemical effect on the glands themselves. Then, at the moment food enters the stomach, these pepsinogen granules are, by slight additional changes, transformed into the pepsin and so poured on the food. Possibly a similar antecedent substance is present in the salivary glands from which the specific element ptyalin is derived, a kind of ptyalino-gen. It is well, however, to keep in mind that the actual presence of granules of the nature just described can be

easily demonstrated in the case of the pancreas and the mucous glands only, and that its application to other glands is upon probable grounds only.

THE INNERVATION OF GLANDS.

That glands are under direct nervous control is a matter of every-day experience. The tear glands respond at once to intense emotions, and the common expression to have one's "mouth water" shows that the salivary glands are directly influenced by states of mind. Such nervous influences are not so apparent in the case of the sweat glands, but even there intense emotion or anxiety may produce a copious sweating even when the surrounding temperature would tend the other way. In the case of the stomach and pancreas there are such evidences of innervation. Secretion in the stomach at once induces secretion in the pancreas, explained only by the fact that these two organs are connected by nerves. There is no more reason why glands should be automatic, that is, independent of nervous control, than why muscles should be. Glandular activity is no less an activity than muscular exertion. The regulation of the periods of secretion so that the product may be available just at the moment that it is needed could be effected only by nervous control. The saliva flows when food is masticated in the mouth, the gastric or pancreatic juices are poured into the alimentary canal as soon as the mucous membrane in stomach and intestine is stimulated by entering foods, while the gall-bladder contracts and pours its contents of bile into the duodenum for the same reason.

The manner of the innervation of glands has, however, been worked out carefully and explicitly in the case of the salivary glands only, and the account here given is that of the submaxillary gland itself, but there is every reason to believe that in the main the nervous arrangement of the other glands is the same. In order to understand how this has been worked out, a few experiments in the stimulation

of the nerves going to the submaxillary gland will materially aid:

1.—*The cerebro-spinal nerves.* If the nerve coming from the brain and going to the submaxillary gland be cut, and the end of the nerve connected with the gland be stimulated, a copious secretion of saliva immediately results. At first the saliva is perfectly normal, but as the gland is being stimulated longer and longer, the secretion becomes more and more watery, and finally contains little else than water and dissolved salts. The ptyalin, the specific element of saliva and the mucin are no longer present. If the nerve or gland be not too much affected by excessive work such a secretion of watery saliva may be continued for a long time.

From this experiment it is evident that the nerve from the brain, the *corda tympani*, as it is usually called, causes an abundant flow of a watery secretion from the gland, but does not seem to be directly concerned in the production of any of the specific elements of the secretion. What the gland pours out is simply material which it has taken from the blood. It is not anything which the gland has made itself. Such parts of a secretion which are derived directly from the blood are called *transudations*, and it seems that the cerebro-spinal nerve is therefore directly concerned with the transudations. These transudations, however, serve to wash the specific elements out of the gland. For this reason the saliva which first begins to flow contains ptyalin and mucin, because these elements were stored up in the gland and were then washed out. But as soon as this stored supply is exhausted nothing but the transudations continue. These transudations may, then, flow from the gland for an indefinite period, because as the blood supply in the gland is kept constant the source from which the transudations are derived does not diminish. When, finally, such a gland stops secreting it is probably more a nervous exhaustion than a glandular one. This will ex-

plain why the flow of tears may continue indefinitely, the lachrymal secretion being entirely a transudation and containing no specific element of the lachrymal glands themselves. It will also explain why by thinking of palatable foods, etc., the mouth begins to water. It is a stimulation of the cerebro-spinal nerve, the result of which is an immediate flow of the transudatory part of the saliva. It must not be imagined, however, that the flow of tears or the flow of this watery saliva is a mere filtration from the blood. It is an actual picking up of these materials from the blood by the gland cells themselves. If it were a mere filtration there is no reason why the tears should not flow at an unvarying rate all the time.

2.—*The sympathetic nerves.* In addition to the cerebro-spinal nerve to the submaxillary gland this gland is supplied with branches from the sympathetic system. When these nerves are stimulated the gland begins to secrete saliva, also, but the saliva is now of an entirely different kind. Instead of being watery it now becomes exceedingly viscid and ropy, and contains a much greater proportion of the specific elements of the secretion. Continued stimulation of the sympathetic nerve may cause the saliva to cease flowing altogether; but this is because the secretion has become so thick and concentrated that it is not able to force its way through the delicate tubes. Evidently the sympathetic nerve has to do with the production of the specific elements themselves, and in no integral way whatever is it concerned with the transudation elements. It seems to govern the production of those things which the gland must make for itself and store up. If, now, after the sympathetic nerve has been stimulated for some time and the saliva has thus been made thick and ropy, the cerebro-spinal nerve be also stimulated, there is at once a copious flow of saliva. Under the influence of the latter nerve large quantities of water and mineral salts are actively picked up by the gland from the blood and passed through into the tubules, washing out the specific elements formed.

There is, therefore, no difficulty in interpreting these phenomena. To restate it, it is this. The gland cells receive two kinds of nerves. First, those from the cerebro-spinal system, which when stimulated cause the transudations to wash the specific elements out of the glands. Secondly, the sympathetic nerves which control the production of the specific elements themselves. The sympathetic nerve is no doubt more or less in action all the time, and in this way the gland is busy in the production of the specific elements in the periods of apparent rest when there is no secretion flowing from the gland, while the cerebro-spinal nerve is called into play at the moment the secretion is wanted, and brings about a copious flow of water and mineral salts through the gland, by means of which these specific elements are carried out. Of course just at this time the stored antecedent granules in the various glands are finally changed into the regular specific elements; otherwise the transudations would not be able to carry them out. For instance, in the pancreas the trypsinogen granules would not be affected by the water and salt secreted, but it would at that point change into the soluble trypsin which is readily washed out.

It was pointed out before that along with the stimulation of the cerebro-spinal nerve there is a stimulation of the vaso-dilator nerves going to the arteries of the glands, so that while the transudations are being poured out of the gland the gland itself seems flushed with the distended arteries. From the foregoing it is evident that the gland is not exerting itself most at the time the secretion is actively pouring out, but that the real constructive period of activity is the one between such times of flow, the period during which the specific element is gradually built and stored up. It was pointed out that the cerebro-spinal nerve seems wholly concerned with the water and the salt transudations, and the sympathetic nerve wholly with the production of the specific elements. While this is in the main true, there are physiologists who believe that the cerebro-spinal nerve

also exerts a slight influence in the production of the specific element, and, on the other hand, that the sympathetic nerve to some extent exerts an influence on the secretion of the water. While such a condition of things is not at all improbable, experiments on glands such as the one just described clearly demonstrate that in the main cerebro-spinal nerves govern transudation, the function of which is to wash out the specific elements when such are produced, while the sympathetic nerve is concerned in the production of these specific elements themselves.

So far there has been considered only the general physiology of secretion; that is, those phenomena which are common to all glands. The special physiology of the individual glands is reserved for a detailed discussion, when these glands are treated in connection with their special functions.

CHAPTER XII.

THE DIGESTIVE ORGANS AND THEIR ANATOMY.

In the discussions in the preceding chapters the blood was made the source of all of the elements needed for the tissues or secreted by the glands. In the chapter on respiration alone was it pointed out that in turn the blood derived its source of oxygen from the air, and that it derived its supply of carbon dioxide from the tissues. In several chapters there is now to be pointed out in what manner the blood, which is the medium between the external world and the tissues of the body, derives its supply to enable it in turn to supply the tissues.

The necessity for such a food supply is entirely too evident to need further comment. An organ stops work soon after its supply of blood is cut off. But the blood is in no sense a living tissue; has no vitality of its own; is, as far as the tissues are concerned, a foreign body; is nothing more, in short, than the circulating store-house out of which, as it passes along, the hungry tissues may pick up what they need for their own life. To cut the nutritive value of the blood down below a certain average composition, or to put into the blood injurious substances will at once react upon the tissues which derive their supplies from it. But there are very few bodies which can at once be carried by the blood and serve as nourishment for the live tissues. Nearly all foods are in a solid state, and in this condition they are unable to pass into the circulation. Even many foods in a liquid condition to begin with, are nevertheless not available as foods when directly placed in the blood. Thus, the albumen of an egg, certainly one of the most nutritious of foods, is to some extent poisonous when in-

jected directly into the blood-vessels, and is not utilized at all as nourishment.

Then again, the vitality of the tissues depends largely upon the constancy and permanency of the blood supply, and to place at once into the blood stream varying quantities and diverse kinds of foods would react at once, and materially interfere with the normal and continued activity of the cells. To transform foods and change them into substances which may be carried by the blood and utilized by the tissues, there is provided by the body one of the most extensive and complicated systems, familiarly termed the alimentary system or digestive apparatus. Before noticing how the foods are affected and in what manner they are prepared for the blood, it is necessary to become acquainted with the anatomy of this system itself.

THE MOUTH.

• The mouth serves as the entrance place for not only the solid and liquid foods, but also for the gaseous food, the oxygen of the air, a food in no less sense than bread and butter. However, in the mouth the solid and liquid foods are carried to the pharynx and gullet and into the stomach, while the gaseous food in the manner already described, is carried to the lungs. The lung is in no far-fetched sense, then, an adjunct of the alimentary canal, intended to digest that food which, on account of its gaseous condition, does not need the action of further juices to prepare it for absorption. Leading out of the mouth are six openings: The two posterior nares, connected with the nose and serving as passage-ways for the air; two Eustachian tubes leading from the back of the mouth to the ear, and to be described further in the chapter on hearing; the pharynx, leading into the gullet, and in front of the pharynx, the larynx, or voice-box leading to the trachea. While the mouth, tongue and teeth figure in an integral way in the formation of speech, we are concerned here only with their digestive function. This is mainly the process of mastication, made possible by

the presence of the teeth for crushing the food and the tongue for manipulating it during this act.

1. THE TEETH.

Arranged in a single row in both upper and lower jaw are the teeth. These appear first as a temporary set about the sixth or seventh month and disappear at about the sixth or seventh year. This temporary set is usually called the milk dentition for evident reasons. It is at once followed by a permanent set, which consists of thirty-two individual teeth, sixteen above and sixteen below. Taking half of either row, the two in front are called the incisors, or cutting teeth. They have a peculiar chisel-like edge, making them specially adapted for cutting. These are followed by a single canine tooth, sometimes called the eye-tooth (in upper jaw). The name canine is derived from the fact that this tooth is especially developed in the carnivorous animals, and is there used for tearing the food. To make it more efficient as a tearing tooth in the carnivora, it is frequently much longer than the others; in fact, sometimes so long as project from the mouth. The canine is followed by two premolars, called bicuspid also, from the fact that they have but two fangs. The premolars are the teeth of the permanent set which have replaced the molars of the milk dentition. Following the two premolars we have three molar teeth not represented at all in the temporary set. These molars are called tricuspid also, from the fact that they have three fangs. Both the premolars and the molars are especially adapted for the crushing and grinding of foods. The last premolar does not usually appear until from the eighteenth to the twenty-fifth year, and has for this reason been called the "wisdom" tooth.

There is a marked analogy between the teeth of man and those of many of the lower mammals, but modifications of this typical arrangement are met with in certain classes of animals. Thus, in animals like the sheep and cow, which are obliged to pick the grass very closely, the upper front teeth

are missing and the lower teeth strike against an upper pad. In the class of rodents or gnawers, which includes such forms as the rat and the squirrel, the incisors are remarkably developed. They keep growing throughout life, and have to be kept short by being worn off against each other. In this way these teeth are kept continually very sharp. It not infrequently happens that such a rodent

breaks off one of the incisors, in which case the opposite incisor no longer worn away, grows indefinitely, and may finally grow around back into the head of the animal and cause its death.

The Structure of a Tooth.

The typical tooth, such as a canine, for instance, consists of three parts—the fang imbedded in the jaw, the neck, and the crown projecting from the gums. If such a tooth be cut in two longitudinally there is disclosed in the center a large cavity known as the “pulp” cavity and opening to the exterior through the fangs. At these points nerves and blood-vessels enter the pulp cavity. The main body of

Fig. 100.—VERTICAL SECTION OF A PREMOLAR OF THE CAT. (After Waldeyer.)

c, pulp cavity; 1, enamel; 2, dentine; 3, cement; 4, dental periosteum; 5, bone of lower jaw.

the tooth is made of a substance known as dentine, or ivory. In composition it is not very different from bone, but histologically it is not the same. Dentine possesses neither Haversian canals nor lacunæ, and so, of course, has no osteoblasts imbedded in its substance. Running, however, from the pulp cavity outward and permeating the dentine everywhere are fine tubules, each about $\frac{1}{5000}$ of an inch in diameter. Near the outside of the dentine these tubules frequently open into large irregular spaces known as interglobular spaces. The function of these spaces is not known.

Fig. 101.—SECTION OF FANG OF HUMAN CANINE. (After Waldeyer.)

1, cement, with lacunæ and lamellæ; 2, layer of interglobular spaces; 3, dentinal tubules.

Through these dentinal tubules, for a little distance at least, arms of dentinoblasts extend, which are immediately concerned with the growth and repair of the dentine. These

dentinoblasts lie next to the dentine in the pulp cavity and are probably not essentially different, except in position, from the osteoblasts in bone. The reason for the absence of lacunæ and Haversian canals in the ivory is of course apparent. Such a system of holes and spaces would materially interfere with the hardness and solidity of dentine and so make it much less serviceable in the crushing of foods.

In the fang this dentine is covered over by a thin layer of cement by means of which it is bound to the jaw-bone. This cement is nothing but ordinary bone, and as such contains lacunæ and not infrequently Haversian canals.

On the crown the dentine is covered over with a coating of an exceedingly hard substance known as enamel. This is totally different from the dentine both in structure and in origin. The dentine is essentially bone, but the enamel is derived from the skin, like the nails of the fingers. There has, however, been such a mineral deposition

Fig. 102.—ENAMEL PRISMS. (After Kölliker.)

A, fragments and single columns of enamel; B, surface view, showing the hexagonal ends of the prisms.

in these epidermal cells as to transform them into the hardest substance in the body. In structure the enamel consists of more or less hexagonal prisms arranged vertically

with reference to the stress to which they are subjected. In a perfectly new tooth which has not suffered any abrasion the enamel is covered over with a slight cuticle, also of skin origin, which, however, at once disappears when the tooth is put to hard use.

Hygiene.

While in the dentine of a tooth a slight growth and repair may be possible, it is not possible to remedy a defect in the tooth when it assumes at all large dimensions, while of course a cracking or loss of the enamel is at once irreparable. As the teeth are almost wholly of a mineral nature they are subject to the action of acids, and as in the decomposition of foods various organic acids are produced there is a constant corroding action going on which may finally destroy the teeth. While the enamel is over them, this corroding action is largely prevented, but as soon as the hard enamel gives way and the acids have direct access to the softer dentine beneath, the corroding influence proceeds more rapidly. This explains in the clearest way the necessity for absolute cleanliness of teeth in order to preserve them.

Around the teeth, sometimes even in spite of good care, there is formed a deposit familiar as tartar. This is not wholly derived from bits of food which have not been removed, but the tartar is mainly a deposit of lime salts derived from the saliva. In ordinary saliva lime salts are present, and as the teeth are continually bathed in such a lime solution a deposition of these salts around the teeth goes on and so gives rise to the crusty tartar. This act of deposition is illustrated in the lime crusts which form on the inside of kettles or boilers in which hard water has been continually kept. When such tartar is merely a pure lime deposit it is possible that it may interfere in no way with the teeth, except, possibly, to irritate the gums, when these are pressed down on the tartar underneath them and so produce bleeding, but most frequently there is deposited along with this tartar and

in it, much decayed food material, in which case the tartar itself with these decaying impurities in it becomes a source of infection and needs immediate removal.

The hygiene of the teeth forms such an integral part of a person's general sense of order and cleanliness that it would be entirely out of place to comment further on it in this connection.

The Development of the Teeth.

As pointed out previously, the teeth when once fully formed are not able to grow or repair themselves in any material way. This is absolutely true of the enamel.

After that has been formed in the first appearance of the tooth, it is never possible to be replaced later. However, with the dentine a slight repairing action may be noticed. If, for instance, on the crown or neck of the tooth where the enamel has been removed, the dentine has been worn away and a cavity so resulted, there is not infrequently deposited in the pulp cavity on the dentine in a position corresponding exactly with the corroded place on the outside a new bit of bone-like dentine which serves to counteract, to some extent at least, the corrosive action on the outside. Even the dentinal tubules which extend into the dentine so softened or corroded become filled with calcareous depositions and the tooth so becomes firmer and consequently more resistant to decay. Reference to the accompanying diagram will explain this. The cement of the teeth is within certain limits easily replaced. It is practically nothing but bone and is secreted by a kind of periosteum which covers the jaw-bone and which dips into the

Fig. 103. — LONGITUDINAL SECTION OF AN INCISOR SHOWING THE REPAIRING OF DENTINE AT *r* AND *r'*, POINTS CORRESPONDING TO PLACES OF DENUDED DENTINE ON THE EXTERIOR. (After Salter.)

It is practically nothing but bone and is secreted by a kind of periosteum which covers the jaw-bone and which dips into the

sockets in which the teeth are held. It not infrequently happens that teeth quite loose are in a short time again firmly set in their places.

Origin of the Enamel.—The manner in which the teeth arise originally may be tolerably easily understood by examining a section from the jaw-bone of a foetus, in which the rudiment of the teeth are just making their appearance. In such an examination it will be found that the first indication of teeth is a pitting in of the epithelium of the mouth (the skin) in the form of a groove, which occupies about that position on the jaw where later the row of teeth is to appear. This groove of epithelial cells grows down into the substance of the jaw, and from this groove there grow out little side projections which soon begin to shape themselves into the forms of the crowns of the intended teeth. This epithelial outgrowth produces the enamel of the teeth, so that this part of it appears in a developing

Fig. 104.—SECTION THROUGH A DEVELOPING MILK MOLAR OF A HUMAN EMBRYO. (After Röse.)

L. E. L., labio-dental lamina; *M. E.*, the epithelium of the mouth; *Z. L.*, dental lamina, spreading out at *P. p.* to form the enamel cap of the future bicuspidate tooth; *Z. S.*, the condensed tissue forming the dental sac.

tooth some time before the body of the tooth, the dentine, arises. The cells of the lowest row of these lateral outgrowths become columnar and elongated and form the enamel prisms. According to some anatomists these hexagonal

prisms result from a direct calcification of these columnar cells themselves, and in this way they account for the hexagonal shape of the prisms. Other anatomists hold that the enamel prisms are formed from secretions which these cells produce at one end. It is impossible to determine just which of these two views is correct, the probability being that the cells themselves become hardened into the prisms, just as in the case of the finger nail similar epithelium cells become hardened into these horny structures. The upper layers of cells of this lateral outgrowth become changed into the enamel cuticle which was referred to as covering a perfectly new tooth.

Formation of Dentine.—As soon as the enamel crown begins to arise in the way just indicated, cells appear immediately underneath it, which begin to deposit dentine next to the enamel. These cells, called dentinoblasts, or by others odontoblasts, secrete a matrix which hardens at once into the ivory. In this matrix these cells extend protoplasmic processes which become imbedded in the dentine, and which in the fully formed tooth are the protoplasmic

Fig. 105.—SECTION OF DEVELOPING DENTINE FROM AN INCISOR OF A YOUNG RAT. (After Schäfer.)

a, outer layer of fully formed dentine; *b*, soft matrix, with a few nodules of calcareous matter already in it; *c*, odontoblasts with arms extending into the dentine; *d*, pulp cavity with contained pulp.

processes lying in the dentinal tubules. These dentinoblasts, however, do not wall themselves in as in the case of bone, but always remain outside of the dentine in the pulp cavity. Thus the dentine surrounding one or more dentinal tubules from the enamel entirely down to the pulp

cavity is the product of a single odontoblast. In an adult tooth these odontoblasts in reduced number may still be found next to the pulp cavity.

The growth of a tooth begins with the crown and extends to the fang. As this growth proceeds downwards the crown is gradually pushed upwards and so soon appears above the gums. While the tooth is thus developing the jaw-bone around it is also developing, and so when the tooth appears it finds itself firmly placed in its bony socket. In the case of the milk dentition the cement which forms seems to be removed by the action of osteoclasts, and so these teeth soon drop out and are replaced by the permanent set. These permanent teeth develop in a way perfectly analogous to that of the milk dentition. From the epithelium groove from which the lateral enamel outgrowths, or milk teeth arise, secondary outgrowths arise which are later on to form the enamel coverings of the permanent teeth. These epithelial cells concerned in the formation of the enamel are called *adamantoblasts*. The epithelium groove of course soon disappears after the lateral outgrowths from it have resulted, and no vestige of it remains in the adult jaw.

2. THE TONGUE.

The tongue is a muscular organ with its base attached to the floor of the mouth and to the hyoid bone, and covered over with a sensitive mucous membrane. On this mucous membrane there are developed three kinds of papillæ. Scattered all over the tongue are small pointed projections known as the *filliform papillæ*. They are not very well developed in man, but are in many of the lower animals. The intense roughness of a cow's tongue is due to these filliform papillæ, while with many of the carnivora these papillæ enable them to scrape the bones and remove from them by their rasping action all shreds of flesh. They function mainly in man to give the tongue a certain roughness so that it may more readily manipulate the food in the act of mastication and in swallowing.

Not so numerous as the filliform, but scattered over almost the entire tongue are somewhat larger, blunter papillæ known as the *fungiform*. The position of these

Fig. 106.—SURFACE VIEW OF THE HUMAN TONGUE. (After Sappey.)

1, 2, circumvallate papillæ; 3, fungiform papillæ; 4, filliform papillæ; 5, oblique folds; 6, mucous and lymphoid follicles; 7, tonsils; 8, tip of epiglottis, 9, median glosso-epiglottic fold.

papillæ may easily be recognized on the tongue in the red-dish spots which mark the tip of the tongue at times. Nerves of taste are distributed to these, and their function is no doubt in connection with this sense.

But the sense of taste is most acute on the third form of papillæ known as the *circumvallate papillæ*. These are the largest of all, and may readily be seen on the back of the tongue, where they are arranged in a V-shaped way, with the open end of the V forwards. There are about a dozen individual circumvallate papillæ in this V. These papillæ do not project materially above the surface of the tongue, but seem to be set down in the mucous membrane of the tongue, being surrounded with a kind of moat not unlike the moat of mediæval castles. In the walls of this moat, both outer and inner, are found special taste bulbs, which will be described later, and which seem especially concerned in the sensation of taste. The presence of these acute taste bulbs at the base of the tongue explains the familiar fact that foods are most sapid at the instant they are being swallowed. Possibly the explanation of this is that with animals at least, and possibly with man, it serves as an inducement to the swallowing of food.

On the back of the tongue just at the pillars of the throat are the tonsils. These are lymphatic glands about the size of a small bean, and apart from their general function as lymphatic glands they seem to serve in no special way in their position on the tongue. The mucous membrane covering the tonsils is deeply pitted at these points, and the position of the tonsils may be readily recognized by these mucous pits.

When by the action of the tongue and pharynx the food is swallowed it is carried over the opening leading into the larynx by the epiglottis, a cartilaginous flap which at the moment of deglutition bends down and covers the passageway to the lungs. The food is thus carried over the epiglottis and is seized by the involuntary muscles of the gullet or œsophagus and so sent to the stomach.

3. THE GULLET OR ŒSOPHAGUS.

The alimentary canal, although more or less arbitrarily divided into the gullet, stomach, and small and large intes-

tines, is in reality but a single continuous tube with but slight local variations. For this reason a description of the coats of the alimentary canal will apply almost equally well to

Fig. 107.—DIAGRAMMATIC SECTION THROUGH THE COATS OF THE STOMACH. (After Mall.)

m, mucous membrane; *d*, duct of gastric gland; *m. m.*, muscular coat of mucous membrane; *s. m.*, submucous coat; *c. m.*, circular muscles; *l. m.*, longitudinal muscles; *s.*, serous coat.

all parts of its course. The alimentary canal is made up of four distinct coats. On the outside there is a serous coat, which is in the œsophagus a reduplication of the pleura, and in the abdomen a reduplication of the peritoneum. Next to this thin serous coat is a thick muscular coat consisting of two portions; an outer portion in which the fibres run longitudinally, and an inner portion in which the fibres run circularly. It is not necessary to repeat that these muscle fibres are of the plain involuntary variety.

Between the longitudinal and circular muscles there run numerous blood-vessels to supply this coat, and there occurs, also, a complex network of ganglia and nerve fibres known as the *plexus of Auerbach*. From this plexus the muscles are directly innervated. Next to the muscular coat is a sub-mucous coat consisting largely of areolar tissue, with contained blood-vessels and lymphatics and serving mainly to bind down to the muscular coat the large mucous coat. In this sub-mucous coat there is a second well-developed network of

ganglia and nerve fibres known as the *plexus of Meissner*. From this plexus the mucous membrane and its glands are innervated. The last, and in some ways the most essential

coat, is the mucous coat, which consists of two portions: A portion next to the sub-mucous, largely fibrous, containing

Fig. 108.—THE PLEXUS OF MEISSNER. (After Cadiat.)

a, a, ganglia; *b, b*, network of nerves; *c*, a small blood-vessel; *d*, a nerve passing to muscular layer of mucous membrane, or to the villi.

numerous blood-vessels, lymphatics, and nerves, and an outer covering of epithelium cells.

In the gullet there is practically no modification of this typical arrangement. The epithelium of the mucous membrane differs, however, from that of the stomach and intestines in being many-layered. However, close to the junction of the œsophagus with the stomach these layers are reduced, and in the stomach and intestines but a single layer remains.

4. THE STOMACH.

The stomach is but a local dilatation of the alimentary tract, and serves as a temporary halting place for the diges-

tion of food. The shape of the stomach is at once evident from the accompanying diagram. It lies mainly to the left side of the body, being displaced from a median position by the large liver which occupies the corresponding right position. The portion next to the œsophagus is the cardiac portion, that portion connected with the intestine, the pyloric portion. The upper curvature is spoken of as the small

Fig. 109.—THE HUMAN STOMACH.

A, cardiac end; c, fundus; P, sphincter muscle, pyloric end; lines indicate longitudinal muscle fibres.

curvature, the lower as the large curvature. The big sac-like dilatation formed by the large curvature, called the fundus of the stomach, varies greatly in size with the varying amount of food taken. In a not-too-distended stomach the dimensions are about nine or ten inches in its long diameter, and from five to seven inches in its short diameter. The outer or serous coat is a part of the peritoneum which lines the abdominal cavity, and which is folded around the stomach as the mesentery. At the front of the stomach, however, this fold is extended downwards over the intestines as a large covering or apron, and is called the *great omentum*. This omentum frequently becomes the seat of fatty deposition, and no doubt materially serves to protect the underlying viscera from changes of temperature.

The muscular coat is a little modified from the typical arrangement, there being three instead of two parts. The

outer muscle fibres run longitudinally. The middle coat is circular, but inside of the middle coat there is a third coat not quite complete, in which the direction of the fibres is oblique. This especial development of the muscles is no doubt intended to make possible the movements of the stomach which accompany gastric digestion.

The sub-mucous coat binds down to the muscular coat the large glandular mucous coat of the stomach. This mucous coat is covered on the inside with a single-layered

Fig. 110.—A CARDIAC GLAND FROM THE DOG'S STOMACH. (After Klein and Noble Smith.)

d, duct of gland; *b*, base or fundus; *e*, ordinary peptic cell; *p*, oxyntic cell.

Fig. 111.—A GASTRIC GLAND STAINED BY CHROMATE OF SILVER, SHOWING THE EXTENSION OF THE LUMEN INTO THE NETWORKS SURROUNDING THE OXYNTIC CELLS, FOR THE EXIT OF THE ACID SECRETION OF THESE CELLS. (After Müller.)

epithelium, which everywhere dips down into the mucous coat and forms pits, or more properly speaking, tubular glands. These glands are the gastric glands. The epithelial lining of the inside of the stomach is continued into

these glands, and forms the secreting cells of the same. These cells lining the glands are spoken of as the *chief cells*, or on account of the fact that they secrete pepsin they are called *peptic cells*. During the resting periods of the stomach these cells become filled with pepsinogen granules, which when digestion commences, are changed into pepsin and poured into the stomach in a manner indicated in detail in the preceding chapter.

But in the gastric glands everywhere except near the pyloric end, there are found underneath these peptic cells, scattered here and there, other more oval cells which are called *oxyntic cells*. This name is derived from the fact that these oxyntic cells produce the hydrochloric acid of the gastric juice. Although these oxyntic cells seem to lie underneath the peptic cells and not to connect at all with the lumen of the gland, special histological methods show that there are delicate canals leading from these oxyntic cells into the duct, so making possible the easy transfer of the hydrochloric acid into the stomach. While most of these gastric glands are simply tubular glands extending the depth of the mucous coat, it not infrequently happens that two or more gastric glands may have a common duct.

Both the mucous and the sub-mucous coat of the stomach are richly supplied with blood-vessels which reach the stomach through the gastric artery, a branch of the coeliac axis. The stomach is supplied with both cerebro-spinal and sympathetic nerves. Branches of the pneumogastric go to the stomach direct, and nerves from the solar plexus just back of the stomach also reach it, while sympathetic nerves run mainly to the gastric arteries.

5. THE SMALL INTESTINE.

The alimentary canal is continued beyond the stomach as the small intestine. There is a tolerably sharp demarcation between the pyloric end of the stomach and the beginning of the intestine, due to the presence of an especially developed sphincter muscle at the pyloric orifice, which is

usually closed, and opens only from time to time to allow properly digested food to pass. The small intestine is much coiled, and has a length of about twenty feet. The coils, however, do not lie superimposed one on the other in the abdominal cavity, but are all suspended in mesenteric slings from the back bone. This suspension not only keeps the folds from resting upon each other, but also prevents them from being relatively displaced. The first twelve inches of the intestine are called the *duodenum* (which means twelve), because in this portion of the intestine but little active digestion is going on, the mixture of the foods with the pancreatic juice and the bile taking place here.

By far the larger portion of the remainder is called the *jejunum*, while the final third is spoken of as the *ileum*. This division is quite arbitrary, and the commencement of the ileum is roughly stated to be that point where the disintegration of food has begun to reach the putrefactive stage.

The structure of the intestinal walls does not vary very much from the typical four coats. On the outside is the serous coat, a reduplication of the peritoneum, and called the mesentery. In these folds of the mesentery the loops of the intestines are of course supported, and through these folds blood-vessels, nerves and lymphatics reach them. The muscular coat consists of an outer longitudinal and an inner circular, between which are the nerve plexus of Auerbach and numerous blood-vessels. The muscular coat is followed by the submucous, in which there are numerous blood-vessels and lymphatics and the nerve plexus of Meissner. The submucous is followed in turn by the mucous coat, the principal coat of the intestine. This mucous coat shows a number of peculiarities. In the first place, it is even in a fairly distended intestine thrown into numerous transverse folds called *valvulae conniventes*, the purpose of which is to afford a greater secreting surface, and at the same time to form lateral pouches in which the food will be detained and so better acted upon by the digestive juices. Close examination of the mucous membrane shows

it to be covered with fine projections not entirely unlike the "pile" on velvet. Examination with the microscope shows

Fig. 112.—PORTION OF THE SMALL INTESTINE TO SHOW THE VALVULÆ CONNIVENTES.
(Brinton.)

that these little projections are finger-like protrusions of the mucous membrane. These are called the "villi," and are in

Fig. 113.—SECTION OF A HUMAN INTESTINAL MUCOUS MEMBRANE, SHOWING THREE COMPLETE VILLI AND SIX CRYPTS OF LIEBERKÜHN. (After Böhm and v. Davidoff.)

an integral way concerned in the absorption of the foods. Between these villi and dipping down into the mucous mem-

brane are small glands called the *crypts of Lieberkühn*. The epithelial lining that covers the mucous membrane is one-layered. This epithelium extends down into the crypts of Lieberkühn and forms in them the secreting cells. It is also continued over the villi. A single villus, therefore, consists of a layer of epithelium covering the fibrous central portion, through which run numerous blood-vessels, while in the center of the villus there is a single large lymphatic called here a lacteal. The rich supply of blood-vessels to such a villus accounts for the efficiency of these structures in the process of absorption, while the central lacteal is the avenue through which the fats reach the body in a manner to be described in the succeeding chapter.

Fig. 114.—INJECTED VILLI OF THE HUMAN INTESTINE. (After Teichmann.)
a, b, lacteals (white); *c*, horizontal lacteals; *d*, networks of blood-vessels (dark).

Nerves and bits of plain muscular tissue distributed through the body of the villus also occur. These bits of plain muscular tissue make possible the slight powers of contraction which are said to materially aid in their absorptive capacity.

The villi extend from the beginning of the duodenum through the length of the small intestine. The crypts of Lieberkühn between them have a similar distribution. In

the duodenum there are found additional glandular structures called the *glands of Brunner*. They are somewhat longer tubular glands which extend down to the submucous coat. The ducts of these open into the intestine between the crypts of Lieberkühn. The glands of Brunner have no especial function, and are in all probability but glands similar to the peptic glands of the stomach, which have reached down into the commencement of the intestine. They secrete small amounts of pepsin which, however, in the intestine are of no value at all. We may therefore speak of these glands of Brunner as ordinary gastric glands which have been continued beyond the pyloric orifice. The crypts of Lieberkühn are similar to the gastric glands, but are much shallower and never possess added oxyntic cells. Of course the secretion which they produce, the intestinal juice, differs materially from the gastric juice.

As the small intestine is to a much greater extent than the stomach the seat of absorption, we find that the walls

Fig. 115.—SECTION OF AN INJECTED ILEUM, SHOWING THE INJECTED LACTEALS, VILLI, TWO PATCHES OF PEYER, ETC. (After Frey.)

a, a, a, villi; *b,* crypts of Lieberkühn; *c,* muscular layer of mucous membrane; *d, d,* patches of Peyer; *f, g, g, g, g,* networks of lacteals.

are richly supplied with networks of blood-vessels and lymphatics. Scattered very generally along the intestine in

the submucous coat are nodules of lymphatic tissue which are called the *patches of Peyer*. These patches may be but tiny nodules invisible to the unaided eye, or may attain the size of lumps distinctly visible and easily felt. Such larger patches may materially distend the submucous coat and may even reach up into the mucous coat displacing the villi in the manner indicated in Figure 115. That such lymphatic glands are scattered so generally through the wall of the small intestine, and even occur in numbers in the mesentery, suggests that the leucocytes which arise in these glands may in some direct way be concerned with the phenomena of absorption.

6. THE LARGE INTESTINE.

The small intestine leads into the large intestine. At the point of the junction there is a valve called the *ilio-colic* valve, so arranged that food may easily pass into the large intestine but cannot pass in the reverse direction. The opening of the small intestine into the large is, however, not a terminal one, the ilio-colic valve being situated on the side of the large intestine. That portion which is back of this valve is spoken of as the blind sac or the *cæcum*. Attached to the cæcum there is a small hollow continuation known as the *vermiform appendix*. While both the cæcum and vermiform appendix in man are quite small and probably have no function at all as far as we know, these structures are very large in the herbivorous animals, and in them serve to hold the food in order to subject it more thoroughly to the digestive action of the juices and the absorptive action of the intestine.

The large intestine differs materially from the small not only in its larger size, but also in its structure. The muscular coats are not so well developed, the circular coat in places being entirely absent. This arrangement of the circular coat gives the wall of the large intestine its pouched appearance. On the mucous coat there are no villi at all. The crypts of Lieberkühn of the small intestine are here replaced by quite similar tubular glands which, however,

do not produce a special intestinal juice, but secrete mucus only. They are; therefore, spoken of as the *mucous glands*

Fig. 116.—GLANDS OF THE LARGE INTESTINE. (After Heidenhain and Klose.)

b, longitudinal section; *c*, transverse section; both showing mucous secreting goblet cells.

of the large intestine. Except that they are a little larger and that they contain numerous mucus-secreting goblet cells, they are analogous to the crypts of the small intestine. The mucous secretion of these glands serves to lubricate the walls of the large intestine and so renders more easy the translation of the foods. The large intestine is much shorter than the small, consisting of three turns only: an upward turn on the right side of the body, known as the ascending colon, a turn running horizontally across the abdominal cavity just beneath the stomach, known as the

transverse colon, and a descending section on the left side known as the descending colon, which then finally through the rectum communicates with the exterior.

7. THE PANCREAS.

The pancreas is a long, slender gland of reddish yellow color and lies immediately below and back of the stomach in the first fold of the duodenum. It is about five or six inches long and from three-quarters to an inch in thickness. In structure this gland resembles very closely the salivary glands, being of the compound racemose type. The secreting cells have the characteristic glandular appearance and are so large as to practically fill the lumen of the tubes. Examined under the microscope the cells at rest may be seen to be more or less filled with trypsinogen granules, while when examined after a period of activity the cells seem clear. In both cases, however, the lumen of the tube is exceedingly small. A large duct runs from one end of the gland to the other and collects all of the pancreatic juice, carrying it to the duodenum. This central duct may be easily seen with the unaided eye as a whitish tube, receiving along its course innumerable smaller branches from the tubules which it passes, and finally, in conjunction with the bile-duct from the liver flows at an oblique angle through the muscular wall of the intestine and pours its secretion into that organ. This duct is called the pancreatic duct, or the *duct of Wirsung*. Sometimes an accessory duct is given off which opens into the duodenum about an inch or more above the main pancreatic duct. Indeed, in some instances this accessory duct may become larger than the main duct. This accessory duct is called the *duct of Santorini*. The pancreas is richly supplied with blood-vessels from the celiac axis, and lymphatics and nerves may be easily traced to it. On account of its action on starches the pancreas is called by the Germans the "abdominal salivary gland." Not infrequently it is referred to by our butchers as the abdominal sweetbread, in this case

not to be confounded with the regular sweetbread of the neck, the thymus gland.

8. THE LIVER.

By far the largest gland in the body is the liver. It has the irregular shape familiar to all, as it is displayed at the meat market. The human liver is divided into two main lobes, a larger right lobe and a smaller left lobe, separated more or less by the round ligament of the liver which is the remnant of a blood-vessel of embryonic life. It measures on an average from five to seven inches in its greatest vertical extent, and its greatest transverse diameter is about the same. In bulk the liver occupies about 100 cubic inches and weighs from three and one-half to four and one-half pounds. It is thus about $\frac{1}{35}$ to $\frac{1}{40}$ of the weight of the whole body. In foetal life it is proportionately, however, much heavier, being at birth sometimes as much as $\frac{1}{18}$ of the entire bodily weight. It has a characteristic dull reddish brown color. The ease with which it may be cut or torn is readily exemplified on the butcher's

Fig. 117.—CROSS-SECTION OF A PORTAL CANAL. (Capsule of Glisson.)

v, portal vein; d, bile-duct; a, hepatic artery; l, lymphatic; b, blood-vessel in the tissue of the canal itself.

counter. It is covered over with peritoneum, but has in addition a covering of its own called the *capsule of Glisson*.

This is a capsule of connective tissue which extends entirely over the liver, but which underneath extends in the form of solid branched trabeculæ up into the gland and forms the framework of its inner structure. The point underneath where this capsule of Glisson enters the liver is called the portal fissure. These trabeculæ of connective tissue are here ramified through the interior, carrying in their ramifications branches of the portal vein, the hepatic artery and the bile-duct. If one should imagine a much-branched elm tree covered with heavy canvas, and this canvas folded around the main stem near the ground, and made, so to speak, continuous with it, he would have an analogy to the structure of the liver, the canvas representing the capsule of Glisson covering the entire gland, but at the portal fissure connected with a system of ramifications extending throughout the entire gland. If, now, we should imagine passing through the stem, and through every branch of this tree, even down to the finest twigs, three tubes running side by

Fig. 118.—LONGITUDINAL SECTION OF A PORTAL CANAL CONTAINING A PORTAL VEIN *P. P.*; TO THE RIGHT AND NEXT TO THE VEIN THE SMALLER BILE-DUCT; AND NEXT TO THIS THE STILL SMALLER HEPATIC ARTERY. THE INDIVIDUAL LOBULES OF THE LIVER ARE PLAINLY SHOWN. (After Kierman.)

side, the analogy would be still more helpful. These trabeculæ which run upward from the capsule of Glisson carry

the same name, so that we speak of the capsule of Glisson in the liver containing the three ducts just mentioned. These ramifications finally surround the real units of the liver structure, which are the hepatic lobules. These lobules are spherical, or on account of being pressed by juxtaposition, polyhedral masses. They are visible to the naked eye, giving to the liver that marked-off appearance readily discernible on a fresh specimen, and accounting for the granular feeling when fried liver is masticated or rolled between the teeth. The lobules are made up of innumerable hepatic cells, arranged more or less in rows, radiating from the center of each lobule outward. Around and between these lobules the final ramifications of portal vein, hepatic artery and bile duct run. These end branches are called respectively the *interlobular portal vein*, the *interlobular hepatic artery* and the *interlobular bile-duct*.

From the plexus of the interlobular portal vein capillaries arise which run into the lobule from all directions in such a way as to meet in the center. This capillary network pervading each lobule is called the *lobular plexus*. While this lobular plexus is formed mainly from capillaries arising from the portal vein, there seems little doubt but that into this same lobular plexus, blood from the interlobular hepatic arteries is poured. We have here then a condition of things in which a single capillary plexus is fed by two streams—a portal vein and a hepatic artery. The question naturally arises, why this mixing of the blood from the portal vein and hepatic artery might not have occurred before entering the liver at all, doing away with a double system of vessels ramifying throughout the substance of the liver. The explanation is found in the fact that the hepatic artery is used mainly to carry nutritious blood to the various ducts in connection with the liver, and to the connective tissue everywhere pervading it, and that its primary function is not to carry blood to the liver cells themselves. It seems, however, very improbable indeed from the size of the hepatic artery, that all the blood passing through it

should be used in merely nourishing inactive ducts and passive connective tissue, and it is therefore quite probable

Fig. 119.—DIAGRAMMATIC REPRESENTATION OF TWO HEPATIC LOBULES. (After Schäfer.)

P, interlobular branches of portal vein; *h*, intralobular vein; *S*, sublobular vein; the lobular plexus of capillaries is plainly shown.

that much of the blood of the hepatic artery is mixed with the blood from the portal vein in the lobular capillaries of each lobule.

After the mixed blood passes through the lobular plexus it is collected in the center of each plexus in a small vein called the *intralobular* vein, a word signifying, of course, the vein within, and not between the lobules. The intralobular veins carry the blood out of the lobules, and uniting with the intralobular veins of neighboring lobules form the *sub-lobular veins*, which, by uniting with other similar veins finally form the *hepatic* veins which carry the blood just passed through the liver in the manner described into the vena cava. The hepatic veins are usually several in number, and as the vena cava runs apparently right through the liver they are very short indeed, and are nothing more than veins in the liver substance itself. The interlobular bile-ducts also send capillary projections into each lobule, which, however, do not meet in the center, each capillary duct ending, or more properly speaking, beginning, blind

near the middle of the lobule. These capillary ducts run in between the liver cells, and into them is poured the secretion of the bile, which then through the complicated system of bile-ducts is finally carried to the intestine.

In order to store the secretion of the liver, so that larger quantities may be available when they are needed, the bile-duct is connected by means of a cystic duct with the gall-bladder, a small muscular pouch several inches in diameter, lying under the liver. The bile reaches this gall-bladder by being prevented from reaching the intestine, the duct leading to the intestine being closed by sphincter muscles, and thus forcing the bile up into the gall-bladder. From time to time these sphincter muscles relax, and with a simultaneous contraction of the gall-bladder the bile is expelled in spurts into the duodenum. That portion of the duct which leads from the liver to where the duct from the bladder meets it is called the *hepatic* duct. The duct leading to the bladder is called the *cystic* duct, while that part of the duct formed by the union of the two and which connects with the duodenum is called the *common bile-duct* (*ductus choledochus*). As stated before, this duct opens with the pancreatic duct.

The liver is supplied with lymphatics, running mainly in the capsule of Glisson. Nerves reach it from the left pneumogastric and from the sympathetic through the solar plexus of the mesentery. Like the blood-vessels, these lymphatics and nerves enter the liver at the portal fissure.

THE DUCTLESS GLANDS.

The various structures so far described in this chapter are structures intimately and integrally connected with the process of digestion. There are, however, found along the alimentary canal, though not immediately connected with it, other organs commonly designated as the ductless glands. While it is probable, in fact known, that the function of some of these glands is not related immediately to the process of digestion, yet it is customary, on account of their

position, possibly, to treat them in connection with the digestive tract. This is at least allowable, since the function of several of these structures is practically not at all understood, and so could not be scientifically treated any better in connection with other topics. These ductless glands include the thyroid glands, the thymus gland, the spleen, the adrenal bodies, scattered lymphatic glands, the carotid glands, and the coccygeal gland.

1.—*The thyroid glands.* The thyroid glands are two large dark reddish, vascular structures situated in the neck just below and to the side of the voice-box. The two lobes are usually connected with a transverse portion called the isthmus. It varies in length, each lobe measuring an inch to an inch and a half, while the thickest portion is about an inch. The isthmus connecting these two lobes is about one-half an inch wide and about three-quarters of an inch long. Examined roughly the structure of the organ seems to be granular. This is borne out by a microscopic examin-

Fig. 120.—SHOWING THE RELATIVE POSITIONS AND SIZES OF THE THYMUS AND THYROID GLANDS IN A CHILD. (After Sappey.)

1, 2, 3, 4, thymus gland; 6, thyroid gland, covered with a number of blood-vessels. All the other numbers refer to blood-vessels.

ation of the gland, which shows that it is composed of innumerable vesicles which are bound together more or less firmly by intervening areolar tissue. Each vesicle is usually quite small, at best just visible to the unaided eye.

However, in certain diseases of the thyroid glands, such as goitre, these vesicles may become greatly distended and plainly discernible to the naked eye.

The wall of these vesicles is made up of a single-layered epithelium, in which the individual cells are somewhat cubical or columnar. In the interior there is found a yellowish fluid, which is no doubt the material secreted by these epithelial cells. This same fluid also occurs in the areolar tissue between the vesicles. This fluid on account of its appearance is spoken of as a colloid substance. In certain forms of goitre this colloid substance accumulates to such an enormous extent as to increase the size of the gland to many times its original dimensions. The connective tissue between the vesicles is richly supplied with blood-vessels and lymphatics, which seems to indicate the important part which this gland plays

Fig. 121.—SECTION OF A HUMAN THYROID GLAND. (After Schäfer.)

Two complete vesicles and portions of three others are shown. The colloid material filling both the vesicles and the spaces between is indicated. In the center of figure is a blood-vessel cut across, next to this a plasma cell.

in the economy of the body. The composition of this colloid material has not been satisfactorily determined. By some observers it is stated that it contains proportionately large amounts of phosphorus. More recent experiments have shown that besides containing substances of an albuminous or proteid nature it contains a compound of iodine called thyro-iodine.

Function.—The function of this gland has not been made satisfactorily clear. When the gland is removed from the body peculiar pathological symptoms result, associated with mental disturbances which finally result in insanity and death. It has therefore been supposed by some physiologists that this gland normally removes from the body a kind of poison which, when it accumulates, causes all these pathological symptoms. Such physiologists would look upon the thyroid body as an anti-toxine agent. In fact, certain observers have tried to establish that in animals deprived of the thyroid body there was actually an accumulation of poisons in the blood to such an extent that when this blood was injected into other animals it poisoned them. The difficulty of taking into consideration all possible errors in such an experiment makes it impossible to rely with assurance upon its results, and more recently physiologists have gone to the view that the thyroid glands do not remove a substance from the body which is injurious, but produce a substance for the body which is not only beneficial but indispensable. Experiments have been made by injecting extracts of the thyroid gland into animals, the result being a beneficial quickening of the general body metabolism. Physiologists holding this view would explain the pathological symptoms which follow the loss of these glands, such as the diminution of muscular strength, failure of the mental powers, swelling of the connective tissues, and excessive dryness of the skin, as a result of the absence of this necessary tonic secreted in the thyroids, and it ought therefore to follow, if this view is correct, that the administration of an extract of the thyroid gland ought to produce the normal condition. It is a remarkable fact that in human beings suffering from such symptoms as the result of the loss of the function of the thyroid, injections of thyroid extract, or even feeding them some fresh gland soon restores the individual to a practically normal condition.

It is unfortunate, from a physiological point of view, that a gland which seems to play such an important role in

the life of the body and which is so indispensable to its existence, should be so poorly understood. Investigators have not, however, abandoned the research, and it is possible that the development of the next few years may throw hopeful light on this subject.*

Sometimes there are found in the immediate neighborhood of the thyroids small nodules of similar tissue which are called *para-thyroids*. These are no doubt identical with the regular thyroid glands in structure and function. When in certain animals the removal of the main thyroid does not produce immediate death, these para-thyroids may be, no doubt, under such circumstances fulfilling the same function.

2.—*The Spleen*. Lying on the left side of the body in a position corresponding somewhat to the liver on the

* With the permission of Dr. Robert Hessler, the Pathologist of the Central Indiana Hospital for Insane, at Indianapolis, extracts from a recent clinical report of his are here added. These extracts are reports of cases of Thyroid Medication.

CASE I.—This is the case mentioned in my former paper; a young man who had lain immovable in bed for over three years, and who could not be aroused by any means; was fed twice a day by means of a stomach-tube. Under constantly increasing doses of thyroid gland he gradually returned to life, but showed a tendency to relapse on withholding the remedy. Under very large doses symptoms of exophthalmic goitre appeared. He has received thyroids since November 1, 1895, and still requires moderate daily doses to enable him to move about. He is in the best ward in the hospital, goes out to his meals, and takes walks about the grounds. Mentally he is sluggish, and is not inclined to exert himself; there is some mental impairment. Whether he will ever fully recover is still a question.

CASE II.—A middle-aged German, cataleptic for three years, retained for a long time any position in which he was placed, even the most awkward. He promptly responded to the thyroid treatment, and in a few weeks was able to be about, and the remedy was discontinued. After gaining strength and regaining the use of his extremities—he had been practically bedfast for three years—he for several months assisted the florist in all sorts of work about the grounds, and ultimately returned home well in body and in mind. He remembered the condition he had been in, and fully appreciated what had been done for him. A long account which he wrote about himself, on recovering, is worthy a psychologist's study. He had realized more or less fully at all times what went on about him, but his actions were dominated by delusions.

CASE IV.—This was a man approaching middle age who had been in the hospital several years before, in a cataleptic condition, but since nothing could be done for him at that time, his relatives had taken him home. He was re-admitted to the hospital early in May, 1896, in a stuporous condition, as if asleep; no mental reactions could be obtained with stimuli of any kind. Sensitiveness to painful stimuli greatly diminished. In poor bodily condition; weight 88 pounds; his normal weight had been about 150. Extremities wasted; little motion of them; in fact, they were almost ankylosed from non-use. Hands and fingers contracted; attempts to straighten them brought on symptoms of pain. After a few days of observation in the hospital he was placed on desiccated thyroids in increasing doses. After a month's treatment, signs of awakening appeared, and in three months there was some activity, both bodily and mental. Massage was actively applied. At the end of September, under a daily dose of thirty-five grains, vomiting and diarrhoea

right, is a soft dark purplish organ called the spleen. Its dark purplish color at once enables the observer to distinguish it from the pancreas, which is light colored. Particularly the spleen is referred to as the "melt." It has no ducts leading from it all. It is supplied from the aorta with a rather large splenic artery and connected with the vena cava with a large splenic vein. It is covered over with peritoneum, but in addition to this has a connective tissue capsule of its own. This capsule is largely fibrous, but contains also bands of plain muscular fibres, to the presence of which the contractions and dilatations which this organ undergoes may be referred. From this fibrous capsule trabeculae extend in through the gland and form a fine network throughout its interior. This network is, of course, almost

appeared—thyroidism—and the remedy was stopped for a few days and then resumed under a decreased dosage of ten grains a day, slowly increased in the course of time. By November he was able to sit up in bed and made attempts to use his extremities; the mental condition was fair. He continued to improve rapidly, and by the middle of January, 1897, he was able to rise and put on his coat; he even attempted to write a letter. During March thyroids were discontinued; the daily dose at that time was twenty-five grains. The patient at this time was able to use his legs to some extent, and by the middle of the summer he was able to walk about unassisted. This recovery was truly remarkable. He has not had any further thyroid medication since March. Unfortunately, mental improvement did not keep pace with the bodily. The patient had been a mild maniac years ago, and symptoms of this would crop out now and then; he is, therefore, still detained in the hospital.

CASE XVI.—Age thirty-three; recently passed the acute mania stage and became chronic. At the beginning of the thyroid treatment he was quiet and well-behaved, although delusional and wholly irrational. Under the influence of the gland he became more active; marked symptoms of acute mania reappeared; the heart acted powerfully, and the eyes bulged slightly. Such a reaction was, of course, not desired, and the remedy was stopped, after having been given for several weeks. He soon relapsed to his former quiet condition.

Conclusions.—My conclusions, based on my experience, may be briefly stated about as follows:

Under moderate continued doses of thyroid gland there is a marked bodily reaction in many cases, but not in all. Some cases require comparatively large amounts before any reaction occurs. There is a distinct stimulation of the nervous system, manifested in various ways, and all bodily activities are increased. Tissue metabolism, especially of the muscular and nervous systems, is markedly increased; a considerable loss in body weight occurs in a short time; on suspending the remedy a rapid gain in weight usually follows. In some cases there is a temporary lighting up of sensory or motor activities, one or both, which soon disappear on discontinuing the remedy. Some cases of a certain type (cataleptics) are benefited permanently; apparently all that is required for a restoration to a life of normal activity is the stimulus derived from the substance of the gland.

In moderate doses no ill results are produced. Under very large continued doses a reaction occurs which is essentially an artificial attack of exophthalmic goitre. Any unfavorable symptoms appearing under large dosage promptly disappear on withholding the remedy.

wholly connective tissue, and so far as structure is concerned reminds one of the connective tissue of lymphatic glands. In the meshes of this connective tissue is the spleen pulp. This is loosely contained and may, when the gland is cut, be more or less completely washed out, leaving the framework exposed. When the spleen is cut and this pulp forced out it looks very much like clotted blood, which in fact it mainly is. Such pulp examined with a microscope is seen to consist of ordinary red and white blood corpuscles, the latter in relatively greater number than in normal blood. Among these are many connective tissue cells, found here, no doubt, for the same reason that they occur in all the connective tissues. Among the white blood corpuscles, however, there may be seen now and then in fresh spleen pulp somewhat larger cells exhibiting to a much greater extent amœboid movements. These cells not infrequently have in them red corpuscles in all stages of disintegration, and from this observation physiologists have naturally come to the belief that these cells in the spleen must be concerned in the destruction of red corpuscles. These cells are called the *splenic cells*.

The blood-vessels of the spleen are peculiarly interesting. The artery on entering the spleen divides and subdivides, but the smaller arteries are not connected with veins by means of capillaries as in other portions of the body, but the arteries open abruptly, right into the spleen pulp, thus allowing the blood to soak at large through the interstices of the gland. On the other hand the veins originate as open ducts collecting the blood which has soaked through the pulp. At the ends of these small arteries, that is, just where they open abruptly into the spleen pulp and to a somewhat smaller extent at the beginning of the veins, there are situated little nodules of lymphatic tissue not unlike the patches of Peyer in the intestines. These may be exceedingly small, or may reach dimensions so as to be plainly visible as whitish specks to the unaided eye. These aggregations of white corpuscles are called the *Malpighian*

corpuscles of the spleen. It must be remembered, however, that the word "corpuscles" is here not used in its usual

Fig. 122.—VERTICAL SECTION OF A PORTION OF THE HUMAN SPLEEN. (After Kölliker.)

a, A, fibrous capsule; *b, b*, fibrous trabeculae running through gland; *c, c*, Malpighian corpuscles; *d, d*, injected arteries; *e*, the spleen pulp.

sense, that it does not refer to a single structure, but to an aggregation of white corpuscles in the form of a lymphatic nodule. In this sense a patch of Peyer in the intestine might be called a Malpighian corpuscle of the intestine. Further, these Malpighian corpuscles must not be confounded with the splenic corpuscles just referred to, which are really true corpuscles, but which are found mainly in the interstices between the Malpighian corpuscles. From the structure of the spleen it will be noticed that it is essentially a lymphatic gland, but that unlike true lymphatic glands blood and not lymph traverses it. By the arrangement of the blood-vessels the blood is brought into close contact with the cells that go to make up the splenic pulp, and it is there no doubt subjected to important physiological modifications, which unfortunately are not sufficiently understood.

The function of the spleen is still a chapter reserved for future investigation. That it is not essential to life is proved

by the fact that the spleen may be taken out of an animal without in any serious way inconveniencing it. It shows a slight connection with the process of digestion in the fact that soon after a meal the spleen becomes materially larger, then contracts again during the fasting period. In addition to these meal pulsations, observers have noticed that it undergoes at all times slight contractions and expansions. They have been stated by some to be at the rate of about one expansion per minute. These secondary expansions are, however, quite slight, and may be due to slight changes in blood pressure. Various functions have been ascribed to it. It has been supposed that red corpuscles were formed here. This is true during foetal life and for a short time after birth, but there is really no evidence at all for the view that in adult life red corpuscles are formed here. Then, on the other hand, it has been believed by many to be a place where red corpuscles are destroyed. In evidence of this fact is cited the observation just mentioned, that certain cells of the spleen frequently have in their interior red corpuscles in all stages of disintegration. A further fact which helps to support this view is the large proportionate amount of iron which is found in the spleen, and it has been believed that this iron comes from the destruction of the iron-containing-haemoglobin of red corpuscles. While there seems, therefore, at present much probability that this view is the correct one, it is not yet an undisputed fact. The ability to produce new white corpuscles has been ascribed to the spleen. This is no doubt true. The presence of much lymphatic tissue in the spleen would make readily possible the formation of new white corpuscles just as in all other lymphatic tissue. Recently the view has been advanced that in the spleen there is formed a kind of ferment which when it reaches the pancreas (through the blood) changes the trypsinogen contained in this gland into the trypsin. There is so little evidence to support this view that it has been accepted by practically no physiologists of any note. In short, we may say of the function of the spleen,

first, that containing much lymphatic tissue, it gives rise to white corpuscles; second, that the splenic pulp is no doubt largely instrumental in removing from the blood passing through it degenerate red corpuscles.

The fact that the spleen may be removed without serious injury to an animal may be explained on the ground that there are many lymphatic glands in the body able to produce white corpuscles, and that the destruction of the red corpuscles naturally done by the spleen might be assumed by the liver, in which, regularly, a wholesale destruction takes place.

3.—*The adrenal bodies.* Situated immediately above each kidney there is a small glandular mass called the adrenal body, or not infrequently, the supra-renal body. The right and left adrenals do not have the same form, but are about the same in bulk. They measure from one to two inches from above downward, and from about one inch to an inch and a half from side to side. Their thickness is only about one-fifth of an inch. From these dimensions it will be seen that they are by no means tiny structures, and from their size and the richness of their vascular supply one might suspect that they play an important role in the

Fig. 123.—SECTION THROUGH THE SUPRA-RENAL BODY. (After Allen Thomson.)

r, kidney; *v*, supra-renal vein; the distinction between cortex and medulla is also shown.

body. Each adrenal body is covered with a capsule of connective tissue through which is visible the somewhat yellowish or brownish yellow gland. The gland itself is composed

of an outer cortical region, of a deep yellow color, consisting of rods of cells and an inner medullary portion of a more blackish color and quite soft and pulpy.

A closer examination of this gland reveals that the cortex consists of a framework of connective tissue, in which are imbedded column-like groups of cells. In these columns of cells there is, however, no lumen visible, so that they are evidently not like the tubular glands found elsewhere. The medullary portion consists of a much looser framework of connective tissue, richly supplied with capillaries, while distributed through the interstices of this framework there are groups of cells which resemble somewhat those found in the cortex. The function of these structures, like that of the thyroid and spleen, is still in doubt. The removal of these bodies is rapidly followed by death. The symptoms which follow such removal are great muscular weakness and relaxation of most of the blood-vessels, and a general prostration. Similar symptoms occur in a disease in man known as Addison's disease, which clinical evidence has referred to pathological conditions of the adrenal bodies. This disease is especially marked by the appearance of bronzed patches on the skin, and so the view has arisen that possibly these supra-renal bodies are concerned in the elimination of an injurious pigment from the blood, which, when it accumulates, produces the general poisonous effects, and finally, if sufficiently concentrated, discolors the skin to a deep bronze. On the other hand, some observations seem to indicate that this gland does not remove an injurious pigment from the blood, but that it adds some beneficial substance which, when removed, leads to the described results. Aqueous extracts of the adrenal bodies have been made and injected into the blood-vessels of living animals with the result that it affected in a remarkable way the action of the heart, the blood-vessels, and even the voluntary muscles. It made the contractions of the heart more prolonged, strongly contracted the blood-vessels, and so produced a great increase in blood pressure and pro-

longed the contractions of the voluntary muscles. The effects of such an injection are soon worn off, showing that the active principle of the extract is soon destroyed or eliminated from the body. It will be seen, however, that at best our knowledge is in a most unsatisfactory state, and while it is possible that these adrenals may be concerned in forming some kind of tonic substance which proves beneficial and indispensable to the proper working of other tissues, it seems more probable that it is concerned with the removal of injurious substances already present in the blood. This latter view is materially strengthened by the observation that Addison's disease, marked especially by accumulation of such pigment, follows abnormal conditions of these adrenal bodies.

4.—*The Thymus Gland.* The thymus gland is a temporary structure which is quite large in early life, reaching its maximum size about the second or third year of life, and then gradually dwindling away until adult life, when it is practically gone. It is situated in the lower region of the neck and the upper part of the chest, and when at its maximum development is quite large. Its dimensions about the time of birth are two inches in length and about one and a half inches in width, with a thickness of about one-

Fig. 124.—PART OF THE MEDULLA OF A THYMUS GLAND, SHOWING SEVERAL OF THE RETICULAR FIBRES, A NUMBER OF LYMPHOID CELLS CALLED THYMUS CORPUSCLES, *a*; AND TWO CONCENTRIC CORPUSCLES, *b*. (After Cadiat.)

third of an inch. In some of the lower animals this gland may reach rather remarkable dimensions. In a calf it may be as much as six or eight inches in length and two or

three inches in width. The gland figures in the business of the meat dealer, and is sold under the name of sweet-breads.

The thymus is made up of two lobes of almost the same size, which lobes, however, usually lie close together, meeting each other at their inner surfaces. In structure the thymus gland is a typical lymphatic gland. It is invested with a capsule of fibrous connective tissue, from which trabeculæ extend into the gland, subdividing it and forming a framework throughout its interior. In the meshes of this framework are imbedded innumerable white corpuscles. The trabeculæ extending in from the capsule divide the interior off into little chambers or lobules in which the corpuscles show an arrangement in two layers, an outer layer of ordinary white corpuscles closely packed, and similar in every way to lymphoid structure wherever found. The fact that these cells are spoken of as the thymus corpuscles must not lead to the idea that they are in any way different from ordinary lymphoid corpuscles. In the center of each lobule the corpuscles are not arranged so closely, and there are found here and there imbedded among the ordinary corpuscles nests of cells which show a concentric structure. These are called the *concentric corpuscles* of *Hassall*. Each nest seems to be composed of a covering of hardened epithelium cells enclosing one or more granular cells. While the meaning of these concentric corpuscles is not wholly clear, there is much reason to believe that they are but remains of a primitive epithelial tube which occurs in a developing thymus and so have no physiological significance.

From its structure it would seem, then, that the thymus gland is but a gigantic lymphatic nodule and as such is concerned in the production of new white corpuscles. That it disappears in advancing life may be easily accounted for by the fact that new lymphatic nodules appear in many other parts of the body which may relieve the thymus from the necessity of further use. That the thymus reaches such a

relatively large size in early life would indicate that either lymphatic tissue has not appeared abundantly in other parts of the body, or that in the growing organism there is an especially great demand for new cells. Unlike, however, ordinary lymphatic glands, the thymus seems richly supplied with blood-vessels. Fine vessels penetrate to the individual follicles, forming a plexus around them and sending converging capillaries into the medullary portion. The lymphatics which transverse the interstices of the gland are very large. It is poorly supplied with nerves, although a few filaments derived from the pneumogastric and the sympathetic system reach the gland by way of its arteries.

5.—*The Carotid Glands.* Situated just above the point at which the common carotid artery on each side divides into an internal and external branch there is a small glandular nodule called the carotid gland. It has a connective tissue capsule, trabeculæ from which extend into the interior, dividing it into small lobules. These lobules are composed of masses of epithelium-like cells, around and between which there are distributed numerous blood capillaries. Their physiological importance may be dismissed by saying that we have absolutely no knowledge as to what their function is.

6.—*The Coccygeal Gland.* The coccygeal gland is a small glandular nodule only two or three millimeters in diameter, situated at the apex of the coccyx. It does not differ materially in structure from the carotid glands, being composed of masses of epithelium-like cells surrounded with blood capillaries. Concerning this gland we are also completely in the dark, both as to the manner in which it develops and as to its function.

7.—*The Pituitary Body.* Situated at the end of the infundibulum of the brain (which see) there is a small glandular nodule about the size of a small pea known as the pituitary body. It is enclosed in a special prolongation of the dura mater and is composed of two lobes. In color it

is of a reddish gray appearance. It owes its name to the belief of the ancients that it discharged the "pituita" (phlegm) into the nostrils. In structure it consists of connective tissue, in which there are imbedded numerous branched cells.

There is possibly no reason for treating of this structure in connection with the organs concerned in digestion, or even in connection with the ductless glands, except for the fact that experiments seem to indicate that its function is closely allied to that of the thyroid glands. Complete removal of the pituitary body causes immediate death. Death is preceded by symptoms such as general prostration and spasms, and mental weakness, which are quite similar to those following the removal of the thyroids. This has led many observers to believe that physiologically the pituitary body is a thyroid, and is able to assume to some extent at least, the functions of these glands. However, the condition of our knowledge is best stated by saying that with the exception of a few hints we have at present no clue to its real physiological value.

CHAPTER XIII.

FOODS AND THEIR PHYSIOLOGICAL VALUE.

Having thus described the structure of the organs concerned in digestion, the next question naturally arising is the necessity for such a system. The body is a machine, and apart from the mysterious property which it possesses, which we call "life," it is subject to all the physical laws which govern other machines. We may even go further, and say that although we do not understand what constitutes life, all experiments force us to the belief that this property itself is never in violation of physical and chemical laws. Machines must be supplied with energy to enable them to do their work. There must be the pressure of steam, the electro-motive force of a dynamo, the momentum of running water, or what not, to set things in motion. As soon as the source of energy is cut off the machine stops. The idea of creating a perpetual-motion machine, one which when set going will create the force with which to run, is a scientific absurdity. Not only have thousands of failures to construct one proved that, but one of the most firmly established laws of science, possibly one of the most fundamental discoveries of this century, has been the law that energy can neither be created nor destroyed. This law is called the "law of the conservation of energy." A great advance was made when it was proved that the energy of the living body is subject to this same law. Formerly it was believed that the working energy of the body was a mysterious kind of vital force which seemed to be in continued spontaneous creation in the body. It may be said that the real science of physiology was born when this notion was abandoned.

While, however, energy is indestructible it may easily be changed from one form to another. Steam pressure may

be changed to motion, this in a motor to electricity, the electricity in a lamp to light, in a coil of wire to magnetism, and in the motor of the street-car back again to motion. While such a change from one form to another is possible and readily accomplished, the change so made is always in definite and fixed proportions. An always invariable and fixed amount of heat is changed into a corresponding certain amount of motion, or vice versa. If in an engine running a factory, lighting and heating it as well, every bit of energy could finally again be collected it would be found to be identical in amount with the original energy producing all, even though in the meantime it might have passed through a half dozen other forms. The forms of energy just mentioned have been forms which might be readily recognized as energy. There is something moving or dynamic about the current of electricity, about the light of the lamp, or the heat in the furnace. Such evident energies are spoken of as *dynamic* or *kinetic* energies. But energy may appear in a latent form. A barrel of gunpowder or a cartridge of dynamite, although neither electrified, nor heated nor in motion, possesses a large amount of inherent energy. But a small spark is necessary to transform what is latent into energy of the most dynamic kind. Such latent or resting energy is spoken of as *potential* energy. The energy which comes from the burning of wood or coal is of this potential kind.

The form of energy most suited to the body is this kind of latent energy. It can be easily demonstrated that the food constituting an ordinary meal, if dried, can easily be made to burn and yield considerable quantities of dynamic energy. Sugar, fats, meats, breads, all these may be made to burn and give up the latent energy stored in them. It is this energy which is the source of supply to the body. As far as our knowledge goes now it has been impossible to get energy apart from matter. In fact, it is impossible to think of energy except in terms of matter, and energy has sometimes been defined as matter in motion, in which the motion

may be either a motion of the whole mass, a molecular motion, or even an atomic one. For this reason the body which desires primarily the energy to make possible its activity, must take into itself large quantities of material in which the energy is bound.

So far we have considered the human body as a machine completely constructed and needing no repair, needing only energy to run it. But it is evident that there are other necessities for introducing outside material into it. For many years of its life it must increase in size, and this it can do only by appropriating from the food those substances which it can build into its own tissues. Even when fully matured there is a continued waste which needs new material to replace it. The necessity for foods, therefore, is two-fold: First, to furnish the material out of which the tissues of the body may be constructed; and, secondly, to furnish material out of which the body may derive the energy required for its activity. In order to understand how much this shall be, it is desirable to examine what the losses of the body are under normal conditions.

THE LOSSES OF THE BODY.

1.—*In Matter.* Careful investigations upon persons of average size and conditions show that in the course of a day there is lost from the body in the form of matter about nine pounds. In this is not included that undigested portion of the food which never really becomes part of the body. About five pounds of this loss is through the lungs. It seems at first surprising to think that even in so short a time as one day there should have been breathed out of the lungs a quantity of gas reaching the amount of about five pounds. It seems not quite so surprising that about three pounds or more of this is eliminated from the kidneys. The remainder is thrown off from the skin or poured as excretions into the alimentary canal. Evidently, therefore, from the mere standpoint of matter it is necessary to put into the body each day nine pounds of suitable substances

capable of replacing these nine pounds of loss. The substances lost from the body are, in the lungs, carbon dioxide and watery vapors; in the kidneys, water and a number of nitrogenous substances and salts; and from the skin, water and salts mainly. The losses of the body in excretions poured into the intestinal canal are certain ingredients of the bile, to be discussed later. Possibly one ought to add in this connection occasional losses of the cuticle of the skin or epithelium cells from the mouth, which, however, do not figure in a material sense in this calculation.

2.—*In Energy.* In energy the losses of the body are mainly of two kinds. By far the greater part of the energy is expended in the form of heat. A relatively small proportion of it gives rise to muscular motion. It is a matter of interest that in our bodies about one-fifth only of all the energy is utilized in muscular activity; but four-fifths in the maintenance of the bodily temperature. While this seems but a small per cent., it is much greater than in even the best of engines, the amount of energy in these to be utilized in actual motion being from one-eighth to one-tenth, while in the ordinary engines possibly not more than one-fifteenth or one-twentieth is utilized. When one remembers that in a locomotive only one bushel of coal out of ten is really expended in pulling the train, and the other nine lost in heating the engine and in friction, one is tempted to believe that the most helpful discoveries of the future may be in enabling us to realize a greater per cent. of the energy in active work.

The amount of heat lost by an average person in one day is tolerably difficult to determine. Experiments have, however, been made, the result of which show that if all the heat radiated from a working body in one day were collected it would be sufficient to raise the temperature of about 100 pounds of water from zero to the boiling point. This, too, seems at first too much when we remember that the temperature of the body remains fairly constant, rarely exceeding that of 98 degrees Fahrenheit. It must, however, be borne

in mind that this temperature is maintained by a continued radiation of heat from the body, or by a loss of heat in the evaporation of the sweat of the skin. Such a continued loss during twenty-four hours would not be inconsiderable. Evidently, therefore, to replace this loss of energy there must be introduced into the body as food, substances which when they are burned will give the amount of heat required, and of course in addition, the energy required for the movement of the muscles, which, as stated, is about one-fifth more in amount.

In giving as the losses in energy muscular activity and heat, no attention is paid to other possible forms of energy in connection with secretion, or with the nervous system. In the former there are probably no other forms of energy concerned, while what the nature of the energy is in nerves and psychic states we are at present perfectly unable to state. That such states are accompanied by the production of heat is a known fact, but that all the energy is transformed into heat is another question.

The exact manner, now, in which the body is able to appropriate these foods and build them up into its own tissues, or the manner in which it derives from these foods the energies it expends, will be more fully discussed in the chapter on nutrition.

THE CLASSES OF FOODS.

It would be entirely out of place here to enumerate the large list of substances which figure as foods. These are sufficiently familiar. A study of the varied menu of our tables shows that all foods may be divided into a few typical classes in which the foods of a class not only closely resemble each other, but in which those of one class are clearly distinguishable from those of any other. These classes are, first, *albumens*, or *proteids*; second, *albuminoids*; third, *carbohydrates*; fourth, *hydrocarbons*; fifth, *inorganic salts*; sixth, *water*.

1.—*The Proteids.* The proteids, or albumens, are foods characterized by containing nitrogen in composition. For this reason they are frequently spoken of as the nitrogenous foods. In addition to the nitrogen they contain carbon, oxygen, hydrogen, and traces of other elements. The proteids are familiar in the form of egg albumen, myosin or the lean of meat, casein, the substance of cheese, gluten, the main ingredient of the grains or cereals, and legumen, a vegetable albumen found in relatively great proportion in peas and beans. All the albumens of our diet probably fall into one or the other of these classes. Meats of different sources are physiologically alike and differ only in the matter of flavor and digestibility; hence all forms of meat would be included under the term "myosin."

These foods are the main and substantial foods, and have always been recognized as the essential foods, without one or more of which it would be impossible to live. Evidently one purpose of foods is to make new tissues; but the tissues, in fact protoplasm wherever found, contains nitrogenous substances closely allied to proteids and albumens, and so it is absolutely necessary that to produce these in the body, nitrogenous foods must be taken. In the carbohydrates and hydrocarbons there is no nitrogen, and consequently if our diet should consist wholly of these the tissues of the body would gradually waste away and a death by starvation would ensue. But these proteids or albumens do not figure as tissue builders only in the body. They are an integral source of energy. Without trying to press an analogy, it may be helpful to recall that many substances having nitrogen in combination are peculiarly well fitted as sources of energy. One needs only to think of gun-powder with its contained nitre, or of nitro-glycerine with its contained nitrogen, or of a number of other energy-yielding substances which depend for this property largely upon the fact that they have in their composition nitrogen. Disregarding here numerous objections which the chemist might urge, it may be said that like these formidable

explosives the nitrogenous proteids of the body are a mild form of explosive out of which, under proper circumstances, large amounts of energy may be utilized. The discussion of the manner, however, in which it is believed to be done is postponed to the chapter on nutrition.

2.—*The Albuminoids.* The albuminoids resemble the albumens or proteids in containing nitrogen. The nitrogen, however, seems in such a combination as not to be available to the body as food, as it is in the case of the proteids. For this reason the albuminoids are not able to replace the proteids. The most familiar example of the albuminoids is gelatine found in soups or used in numerous desserts. This gelatine is derived from the connective tissues.. It contains carbon, oxygen, hydrogen, nitrogen, and traces of other substances, resembling, therefore, as just stated, the proteids; but the contained nitrogen seems not to be assimilable by the tissues, and so this food must figure in the body rather like a non-nitrogenous than a nitrogenous food. Regularly, however, the amount of albuminoids taken as food is so small that it does not figure materially in the economy of the body at all.

3.—*Carbohydrates.* In the carbohydrates are included the starches and sugars. The name "carbohydrates" naturally suggests carbon and water as entering into their composition, and such is, in a certain sense, true. All carbohydrates are composed of carbon, hydrogen and oxygen, but the hydrogen and oxygen are present in the proportion of water; that is, two atoms of hydrogen to every one atom of oxygen. An important point is that they contain no nitrogen. The composition of the commoner carbohydrates will easily explain this. Thus the composition of cane sugar is, $C_{12} H_{22} O_{11}$; of glucose, $C_6 H_{12} O_6$; of starch, $C_6 H_{10} O_5$.

The physiological value of these foods lies in the fact that they figure as sources of energy. It will be pointed out in the following chapter that probably the main source

of muscular and heat energy is derived from the carbohydrates. They, too, form the bulk of our foods, there being few dishes indeed of which either the starches or the sugars do not form an integral part. In addition they are perhaps the most digestible of all foods, and finally a reason not to be neglected, they are possibly the cheapest of foods. It seems a rather queer coincidence that the carbohydrates are the foods best suited to the process of digestion, best suited as sources of energy, best suited to the palate, and finally, best suited to our expenses. These coincidences are, no doubt, the result of dietary evolution. The close relationship of the starches and sugars is evident from the ease with which the starches are changed into sugars or sugars into starches.

4.—*Hydrocarbons*. In the hydrocarbons are included the fats and oils. As indicated by their name they contain mainly hydrogen and carbon. A little oxygen is also in combination, but the hydrocarbons differ essentially from the carbohydrates in the fact that the hydrogen and the oxygen are not present in the proportion of water. Compared with the carbohydrates the hydrocarbons contain relatively more carbon and hydrogen and less oxygen. For this reason when they are burned they give rise to much more energy. There would be quite a material difference in the amount of heat liberated between the combustion of a barrel of sugar and a barrel of oil. It is for such reasons that the fats are peculiarly well suited as a diet in winter or in colder climates, and the Esquimau who drinks his blubber supplies himself with one of the best foods for the liberation of heat. The distinction between fats and oils is a rather arbitrary one. Hydrocarbons which at ordinary temperatures are more or less solid, are spoken of as fats, those which at these temperatures are in a liquid condition are called oils.

It is well to bear in mind that fats contain no nitrogen, and that therefore their physiological value in the body is similar to that of the starches and sugars. It would be impossible for an animal to live long if its diet were limited

entirely to fats, or even to fats, starches and sugars. While the fats are sources of greater energy than the carbohydrates, and so better suited for colder climates, they seem not so well suited for temperate climates, and not at all for tropical regions. Even in the latitude of Indiana, the fats and oils have not nearly the general food value of the carbohydrates. Used to supplement the proteids, starches and sugars, they are of course very desirable. The commoner examples of the hydrocarbons are butter, lard, tallow, and the vegetable oils.

5.—*The Inorganic Salts.* In the common use of the term "food," such articles as common and other inorganic salts are not included, but there is as much of a necessity for the presence of some of these salts to make possible the normal functions of the body as there is that proteids, sugars and fats shall replace the waste. With the exception of common salt, which is added as a special ingredient, usually however more for the palate than for its physiological value, the other inorganic salts reach us as regular ingredients of the foods. In nearly all of our solid foods there is a small proportion of mineral matter. This may easily be demonstrated by burning bits of these foods. There are practically no foods which do not leave, when burned, bits of ash. This ash of course constitutes the mineral salts contained in the original substance. While all of these salts do not find their way into the body, the body is able to dissolve and assimilate such of them as are especially needed in the work of the tissues for the building up of mineral constituents of such tissues as bone or enamel. A few of the commoner mineral salts which are required in the body are here given.

For the growth of bone there are required salts of *magnesium* and *calcium* (lime); for the hæmoglobin of the blood, traces of *iron*; for the blood and lymph of the body, considerable quantities of *common salt*; as an integral portion of the red corpuscles and other tissues, *potash* salts.

While these are the main mineral ingredients a chemical examination of the body would reveal small traces of quite a number of additional inorganic salts, which may be omitted here. Not only are these salts needed to build up the mineral constituents of tissues, such as bone or enamel, but they are also needed to make possible the proper working of the tissues. Thus it is known that animals from which common salt has been kept will become materially deranged, suffering what is called a "salt craze," and the continued withholding of the salt may finally induce fatal results. The exact manner in which this salt figures will be treated further on.

6.—*Water*. On account of its abundance and free access everywhere, water is not classed as a food, but is such in an essential way, although of course no energy can be directly derived from the same; but as an agent for dissolving other foods, as an ingredient forming by far the largest amount of all the tissues, it plays a first role in digestion and nutrition.

A MIXED DIET.

Very few of the foods as they are served to us on the dinner table belong wholly to one or another of these classes. In nearly every case they are mixtures of some or all of them, and their dietetic value will depend upon the relative proportions in which they contain these classes as ingredients. The multitude of dishes ranging from the highly flavored and seasoned ones of tables of plenty, down to the simpler foods of the peasant's meal, are but mixtures in varying proportions. The different character which the varying dishes possess is usually much more a matter of flavor or condiment than it is a matter of nutritive value.

In order to fully understand the nutritive value of the food then, and leaving out entirely the matter of flavor, the influence of which ceases with the palate, it is necessary to

make an analysis of these mixtures and to determine the amounts of each one of the classes just mentioned. The accompanying table, modified slightly from Herman, shows in a very striking way the composition of most of the commoner articles of food. By reference to it it will be seen that the animal foods, such as the meats, contain very little of carbohydrates, but relatively much of proteids and fat. Of course the percentage of fat will vary within wide limits, and will depend largely upon the condition of the animal examined. The leaner the animal, evidently the less proportion of fat and the relatively larger proportion of proteid. On the other hand, meat in which there is a good deal of fat might finally have the fat in excess of the proteid, a condition for instance found in ordinary breakfast bacon. For this reason the animal foods, that is the meats, have always been looked upon as the chief sources of the nitrogenous foods, and as nitrogenous foods can not be dispensed with in the diet, these foods have become popularly viewed as almost if not wholly indispensable.

On the other hand, the vegetable foods are quite sharply distinguished by their relatively large amount of carbohydrates and rather small amounts of proteids and fats. Thus the food value of the potato consists almost wholly of the starch which it contains. Rice is nearly all starch. Even in corn the starch is the largest ingredient, although in it there are not inconsiderable quantities of proteid. In wheat, in which the proteid gluten forms quite an integral part of its composition, the carbohydrates occur in large proportion. A rather remarkable exception of what has just been stated occurs in the composition of peas, beans, and other leguminous foods. In these the percentage of proteid actually exceeds that found in meats. This explains why these vegetables have commonly accredited to them such a high nutritive value, and why sometimes in cases of military operations when it is difficult to transport meats, beans have been found a satisfactory substitute.

By reference to the table, an interesting comparison may be made between the composition of cow's milk and human milk. It will be seen that cow's milk contains relatively more proteid, but on the other hand, less sugar and less fat. For this reason, when cow's milk is to be rend-

Fig. 125.—TABLE GIVING RELATIVE COMPOSITION OF THE COMMONER FOODS.

ered as nearly of the composition of human milk as possible, it is diluted with water in order to dilute the extra amount of proteids in the cow's milk, and then there is added cream and sugar to bring these up to the increased percentage in the human milk. The interested reader will be able to answer so many questions bearing directly on these points here under consideration by referring directly to the table given, that an extended comment on the composition of the commoner foods is deemed unnecessary.

THE RELATIVE AMOUNTS OF THESE CLASSES OF FOODS REQUIRED BY AN AVERAGE INDIVIDUAL AND THE VALUE OF A MIXED DIET.

The experience of every one has shown that it is not desirable to limit one's diet exclusively to one kind of food. If one had nothing but meat he would get much more nitrogen than would be necessary in trying to get the amount of carbon which the body requires, the relative amount of carbon being so small in the proteids. If one limited his diet to a substance which was rich in fats and sugars, but contained only traces of nitrogen, he would have to eat unnecessarily large quantities of fats and sugars to get the proteid necessary for his body. The most sensible way, therefore, of determining the composition of one's diet is to take enough proteid food to give to the body all the nitrogenous food it needs, and then to supply it further with the necessary amounts of carbon and hydrogen, to take foods especially rich in these, such as fats and sugars.

A very natural question is: What are the relative amounts of these classes of foods which an average working body needs, say in a day? A great many and careful experiments have been made and the results of these do not vary materially. We may, therefore, give the average figures with much probability that they state the correct condition of things. In an experiment by Pettenkofer and Voit on a workingman twenty-eight years old, weighing about 150 pounds, it was found that when not at work he needed

137 grams of proteid.
72 grams of fat.
352 grams of carbohydrates.

On a day when this same workman was at regular work he consumed

137 grams of proteid (same as when at rest).
173 grams of fat.
352 grams of carbohydrates.

It will be noticed that the extra work entailed an extra consumption of fat. Other observers have changed this experiment just a little. They, too, found that the amount of

proteids needed either at work or at rest was about the same. They did not, however, increase the amount of fat given when working, but made the increase in the carbohydrates, and then found that under such circumstances the man to be satisfied consumed much larger quantities of these.

Similar experiments were tried on a young physician, whose diet in one day consisted of:

127 grams of proteid.
89 grams of fat.
362 grams of carbohydrates.

As average figures, therefore, the following little table may suffice:

Water.....	3,000	grams.
Proteids.....	131	"
Fats.....	88	"
Carbohydrates.....	400	"

In such an average diet there are 20 grams of nitrogen and 312 grams of carbon. This proportion is about the proportion normally desired by the body. These 20 grams of nitrogen could be secured from the following amounts of foods:

Cheese.....	272	grams.	
Peas	520	"	
Lean meat.....	538	"	
Wheat flour	800	"	
Eggs.....	900	"	(about 18 eggs.)
Milk.....	3,000	"	
Potatoes	4,600	"	
Turnips.	8,700	"	

A glance at the figures just shown will give at once the relative nutritive value of the main foods. Cheese, consisting almost wholly of casein and being in tolerably compact form, is probably by weight the most nutritious. Eggs, on the other hand, in spite of our notion that they are so nutritious, would not yield to the body the required amount of nitrogen unless the diet should average eighteen or more eggs per day. In order to get sufficient proteids out of a diet of potatoes it would require the consumption of a perfectly unwieldy lot, while if the attempt should be made to

get the necessary amount of proteids from turnips, for instance, an amount not less than 8,700 grams would have to be consumed each day. Evidently, therefore, it is desirable that the body should derive its nitrogen supply from those foods which appear first in the table just given.

The 312 grams of carbon which on an average the body needs per day might be derived from the following amounts of foods:

Fat meat	450	grams.	
Corn meal.....	800	"	
Wheaten flour.....	824	"	
Rice	900	"	
Peas	1,000	"	
Cheese	1,200	"	
Eggs.....	2,200	"	(about 4½ eggs.)
Lean meat.....	2,600	"	
Potatoes	3,100	"	
Milk	4,600	"	
Turnips	10,000	"	

These figures at once give us a clue as to the most desirable kind of a diet. It will evidently consist first, of one or more of those substances which are very rich in proteid, such as cheese, peas or beans, meat, cereal flour or eggs, in order to get the proper nitrogen supply, and then for the carbon needed to turn to the second table and get either the fat meats which are especially rich in carbon, or else some of the more starchy foods like corn, wheat, rice or potatoes.

FLAVORS, CONDIMENTS, AND STIMULANTS.

In describing the classes of foods so far, it has been done without very much attention to the distinctions which the palate would make. In the actual eating of foods these secondary flavors and condiments not infrequently play a very determining role. However, all these flavors, no matter how pleasant they may be to the palate, have practically no digestive value at all, and so for pure physiological reasons need not be considered. The dainty distinctions of taste which the various kinds of meats afford

cease as soon as the food has passed the tongue. Even the hundred and one varieties of flavors of our fruits, and the artificial flavors of our desserts share the same fate. Salt, of course, which is sometimes viewed as a seasoning substance figures as a food, but the peppers, or spices, and the mustards are foods in no sense. We derive no nourishment from them, and they serve merely to give gist to the taste, and sometimes by their stimulating action to arouse the often too dormant digestive organs. To this same class belong the teas and coffees. These now almost universal drinks owe their popularity to peculiar organic compounds called theine and caffeine, respectively, which, while of no nutritive value, have a slight stimulating effect. In addition to this a cup of hot tea or coffee during meal time is frequently quite potent to arouse the stomach to secretion, a result which might, however, be equally well brought about by drinking a glass of hot water. The rather baneful effects which follow from an excessive use of these are too well known to need mention here.

ALCOHOL.

Almost as far back as history carries us, man has more or less generally added alcohol in some of its forms to the articles of his daily consumption, and even at this present day the wines and beers are in many places regular dishes at the table, and the question naturally arises, what the nutritive value of this substance is. Alcohol is, of course, never taken in its pure form, but in varying grades of dilution as given in the table below:

Rums and whiskies from	60 to 80 per cent.
Brandies	“ 40 to 60 “
Wines ranging from	40 down to 5 per cent.
Beers “ “	4 “ 1 “

Ordinary commercial alcohol is a colorless liquid of a peculiar penetrating odor and of a very inflammable nature. It is used in the arts very extensively as a solvent for innumerable substances, and in the sciences it is used in

large quantities as a preserving fluid for anatomical and zoological specimens.

It is produced by a process called fermentation. This is a process brought about by a little plant called the "yeast plant," which by its action upon sugar converts it into alcohol and carbon-dioxide gas and several minor products. In the distillery or the brewery this process of fermentation is allowed to go on until the desired per cent. of alcohol has been reached. The carbon dioxide gas is allowed to escape, and gives to the fermenting vats their frothy or "brewing" appearance. The condition of things in the making of yeast bread is the same. Here, too, some yeast which has either been specially put in, or else allowed to fall in from the air, acts upon some of the sugar in the dough, resulting in the formation of alcohol and carbon dioxide gas. The carbon dioxide gas in its attempt to escape from the dough forms innumerable little bubbles throughout it, and so causes the bread to "rise" or become light. The alcohol, of course, evaporates in the process of baking. The same thing is again illustrated in the familiar canning of fruits. Here the fruit to be preserved is boiled, the primary intention of which is to destroy all germs and all yeast plants in it, and then the fruit before it has a chance to cool is put into jars and these then hermetically sealed. If, however, the sealing is defective and air, as we say, gets in, fermentation is soon set up and the sugar in the fruit is ushered along in the process towards the formation of alcohol and remoter substances. It is not, however, the air which sets this process going. It is the introduction of some yeast plants along with the air which is the source of the trouble.

The chemical and physical properties of alcohol in its various forms need not be dwelt upon here, the primary question in this instance being its physiological effects. This, in a general way, is its apparent stimulating power. Administered to animals it quickens, for a while at least, the general tone of nearly all the organs. It produces a tem-

porary exhilaration which is pleasant, and which no doubt explains the desire which has so generally prompted mankind to use it. There are so many good books now available giving the detailed and specific action of this substance on the various organs, and on the body in general, that such a detailed account is deemed unnecessary here. That alcohol taken in excess produces derangements of the most serious nature in almost all the organs, is a point which no man can doubt who has seen the brutish drunkard lying in the gutter. Whether alcohol in moderate quantities is a food or not, whether in small amounts it may not be helpful, is a question which does not concern us here. Suffice it to say that all physiology and possibly all medicine has shown conclusively that there is absolutely no necessity for a sound man to add alcohol in any of its forms to his daily diet. The person who persists in doing so must seek his reason elsewhere, while the fact that in innumerable instances it has done unspeakable harm, is equally well established. Without denying for a moment, or disregarding the effect of alcoholic excesses upon the various tissues of the body, the point remains that the truest reason against the use of this substance is a moral one. The fact that the heart of the toper is unnaturally stimulated by his whiskey, is a very insignificant fact compared with the more serious one that this whiskey in its effects has broken possibly a wife's and a mother's heart; the fact that the drinking of alcohol lowers the temperature of the body of the toper is a very trifling fact compared with the more awful one that it has given babies cold feet for want of shoes, and wives cold backs for want of warm clothing; that it has made homes cold, and has reduced the warmth of a thousand friends. The fact that it may curdle the liver is of small consequence when compared with the more serious fact that it too frequently curdles the sentiments, the hopes, and the aspirations. That alcoholic excesses may produce the ugly ulcerations of the drunkard's stomach is possibly not so

lamentable as the many blotches on virtue which it has produced in our industrial civilization. A certain firm on one Saturday evening paid out to its workingmen four hundred marked ten-dollar bills. The following Monday one hundred of these marked ten-dollar bills were deposited in the city banks by different saloon keepers of the place. When one remembers how many shoes, how many dresses, how many pieces of nutritious meat, how many little toys for playful children, how much happiness, in short, for innumerable homes might have been purchased with these one hundred marked ten-dollar bills which found their way into the saloons, one need not be told further about the lamentable physiological and moral effects. A mighty step in the right direction will have been made when every young person fully realizes that by avoiding the demon of drink the chances are greater that he will always have an abundance of good friends, that he will be able to enjoy what is best in life, that he will be a helpful member of his community and that he will always have a dollar in his pocket with which to buy bread for himself and his own.

CHAPTER XIV.

DIGESTION AND THE DIGESTIVE AGENTS.

HISTORICAL.

Our knowledge concerning the process of digestion does not reach back very far. The notion of the ancients was very primitive indeed. They likened the digestion in the body to a kind of cooking, and in the middle ages this notion was carried so far that they actually thought one purpose of the animal heat of the body, especially the warmth of the internal organs, was to cook the foods. It was as late as the seventeenth century before definite notions of digestive ferments in the stomach arose; but these ferments were looked upon as causing only a very fine mechanical separation of the food. However, Réaumur, in 1752 proved that the agent of digestion was the gastric juice, and that this digestion could be accomplished without any mechanical helps. The sour re-action which Réaumur had noticed was established by Prout in 1834, to be due to free hydrochloric acid. Two years later, in 1836, Schwann discovered the pepsin. In 1834 a Canadian by the name of Beaumont was enabled to make a series of observations on a man whose stomach had been exposed by a wound, and upon which the digestive processes could be fairly accurately followed. In the same year Eberle succeeded in making artificial gastric juice, and conducted experiments in digestion with the same. The sugar-forming action of the saliva was discovered by Leuchs in 1831. Our knowledge of the digestive processes in the intestine did not begin until 1848, when Claude Bernard established the fact that pancreatic juice digested fats. Nine years later, in 1857, Corvisart discovered that pancreatic juice digested

proteids. Although first discovered by Corvisart the proteid-digesting nature of pancreatic juice was finally worked over and established with its present exactness by Kühne in 1867. The intestinal juice was first secured in a pure form by Thiry in 1865.

THE DIGESTIVE AGENTS.

We have now to consider the various changes, chemical and physical, by means of which the solid and usually insoluble food is converted into a liquid form, suitable to be absorbed from the walls of stomach and intestine and passed into the blood. The process of digestion begins, of course, in the mouth. No attention is here paid to peculiar changes helpful in the process of digestion which have been brought about by the cooking or baking of the intended food. Thus it is a familiar fact that the crust of bread is more digestible than the inner part, the process of baking having changed the starch in question into a form which is more easily soluble. The first step in the digestion, as far as the body is concerned, is that of mastication. This is merely a mechanical process by means of which the food is broken up and so enabled to be swallowed. During the process of mastication, however, the food is mixed with the first of the digestive fluids, called the "saliva." The salivary ducts of the parotid and submaxillary glands open at the base of the molar teeth and are so arranged that bits of saliva are introduced whenever the molars are inserted into a morsel of food. In addition to this, of course, a good deal of saliva flows into the front part of the mouth from the sublingual gland, and is there more or less thoroughly mixed by the rotating action of the tongue.

1.—*Saliva and Salivary Digestion.* Saliva is a clear, transparent liquid when filtered. When taken from the mouth it is somewhat cloudy, owing to the fact that it has solid substances in it: bits of food and epithelial cells which have been detached from the mucous membrane of the

mouth. Very frequently, too, white cells, probably identical with white blood corpuscles are present. These are corpuscles which have probably wandered out from deeper tissues along with the secretion. They have been called salivary corpuscles, although now recognized as nothing more than escaped leucocytes. Saliva is a little heavier than water and is alkaline. The quantity secreted in a day is, of course, subject to the widest variations, varying from 200 to 2,000 grams. Saliva contains the following constituents in 1,000 parts:

Water.....	994.2
Mucin.....	2.2
Ptyalin	1.3
Inorganic Salts..	2.2

The inorganic salts are largely chloride of potassium and sodium, and phosphates of calcium and magnesium. These inorganic salts in the saliva are interesting from the fact that small amounts of them are deposited around the teeth and give rise to the formation of tartar. The mucin present in the saliva is ordinary mucus or phlegm, and is really an addition to the saliva from the mucous glands in the mouth. This mucus has no distinct value further than that by its ropy and sticky nature it serves to hold bits of the food together and so makes swallowing easier. Incidentally along with the saliva it serves to keep the mouth moist. The main and distinct constituent of saliva is the *ptyalin*. This belongs to the class of substance called enzymes, or ferments, and has the property of being able to convert starch into sugar.

THE THEORY OF HYDROLYSIS.

As the term "enzyme" or ferment occurs repeatedly in physiology (the pepsin in the stomach, the trypsin in the pancreas, and others being ferments), a word in explanation of these substances and the manner in which they are supposed to act is given.

There are two kinds of ferments; one, that of living ferments, of which the many forms of bacteria and the yeast

plant are good illustrations. These ferments are really living beings which are able in some way to set up chemical processes which we have chosen to call fermentation processes. The other class consists of unorganized, dead substances. They are chemical ferments. To this second class belong almost all the digestive ferments of the body. Ferments have the power of breaking up certain substances and changing them into new compounds. Thus ptyalin, as just stated, changes starch into sugar. It is probable that these ferments produce these results in the following way: They cause the substance to be changed to take up one or more molecules of water, and then split this combination into two or more smaller bodies. This action is well shown in the change which takes place in cane sugar. Not infrequently cane sugar is changed into two sugars called dextrose and levulose. This change from cane sugar to dextrose and levulose is represented chemically in the following equation:

A similar change occurs in the mouth. Under the influence of the ptyalin the starch is made to combine chemically with more water and the resulting molecule is then split up, sugar being the result. Ptyalin is present in many of the lower animals, especially the herbivorous animals, but seems to be absent in the carnivora. It was, until recently, believed that the sugar which resulted from the action of the ptyalin on starch was ordinary grape sugar, but later investigation has shown that this is incorrect, and that the resulting sugar is *maltose*, a sugar very closely related chemically to ordinary cane sugar. However, the starch is not at once changed into maltose, but there seems to be between the beginning starch and the final maltose a number of intermediate stages with which, however, in this elementary treatise we are not concerned.

The physiological value of ptyalin is evident. Starch is insoluble, and could not pass through the walls of the ali-

mentary canal, but by its conversion into maltose this difficulty is at once remedied, maltose being quite dialyzable. On account of the short time during which the food remains in the mouth but a very small part of the starch is converted into maltose. But we shall see in the discussion of the pancreas that this process is again picked up in the intestine and there completed. The ptyalin is unable to act in an acid medium, and so as soon as the food reaches the stomach its digestive action ceases, but when later the food is passed into the small intestine and the acid of the stomach gives way to the alkalinity of the intestine, the saliva renews its digestive action, so that possibly the greatest effect of the saliva is produced, not in the mouth, but in the intestine. The digestive action of the ptyalin may be easily demonstrated by taking a dish of boiled starch and adding a little saliva containing ptyalin to it. By keeping this dish then at a temperature of about 98° Fahrenheit the starch is rapidly converted into sugar and may be detected quite easily by the taste and by chemical re-actions.

2.—*The Stomach and Gastric Digestion.* The process of digestion in the stomach is almost wholly a chemical one and is only incidentally mechanical. The food remains here one or more hours, varying with its digestibility, during which time it is subjected to a slight churning process. Slight peristaltic movements creep across the stomach, the effect of which is to more or less mix and re-mix the gastric contents and so materially aid the juice in reaching all the particles of the food. The stomach owes its power to digest to the gastric juice. This juice is by no means a simple substance, but is a mixture of several things. Its composition is in 1,000 parts about as follows:

993	parts	water.
2	"	hydrochloric acid.
3	"	pepsin.
2	"	salts.

In addition to these substances, which can be more or less quantitatively determined, there are present in the gastric

juice several other substances which it is not yet possible to secure in a pure form, but the presence of which can be easily demonstrated by the actions which they exert. One of these is the ferment called "rennet," a ferment which coagulates milk. Traces of mucin also are present.

a.—Pepsin. The principal ingredient of gastric juice is the ferment called "pepsin." This is an organic compound of an albuminous nature, possessing almost all the characteristics of ordinary peptones. It has the property of digesting albumens and albuminoids, transforming the albumens into soluble peptones and the albuminoids into dialyzable gelatin. It is able to effect these changes, however, only in an acid solution, which explains the presence of the free hydrochloric acid in the stomach. In fact, it is possible that the pepsin and the acid may in conjunction, as a pepsin-acid, effect these changes.

The change from the non-dialyzable and sometimes solid proteids to the liquid and dialyzable peptones is, however, not a direct one. As in the case of the conversion of sugar into maltose by the ptyalin so here there are between the beginning proteids and the final peptones a number of intermediate stages designated as acid albumens and proteoses. By the experiments of Kühne and Chittenden quite a number of these intermediate products have been determined and studied, and these experimenters have worked out a table showing the stages through which the proteids pass toward the final peptones. However, in an elementary text-book these changes are too intricate to be dwelt upon, the significant fact being that a large part of the proteids of the stomach are converted by the continued action of the gastric juice into peptones, while the intermediate stages and any proteids not affected by the gastric digestion are passed into the intestine and there their change into peptones is completed by the action of the pancreatic juice.

It must not be understood that a proteid is merely a solid albumen and a peptone a liquid albumen. The vital

difference between a proteid and a peptone is in the power of dialysis. A proteid dialyzes little if at all, while a peptone does so readily. Egg albumens even when in a liquid form, as we find it in an egg which has been subjected to the process of incubation for several days, is by no means a peptone. In spite of its liquid form it is but little dialyzable, and if taken into the alimentary canal would have to be transformed into dialyzable peptones in no less a way than a bit of solid meat. Peptones further possess the property of not being coagulated when subjected to heat. This is, of course, also true of certain proteids; as, for instance, the proteid in milk which may be boiled without coagulating the milk. But the peptones, in addition to not being coagulated by boiling, are not precipitated when treated with alkalies, mineral acids or various salts. In short, a peptone is an albumen in such a liquid form that it is easily dialyzable and is not taken out of its liquid form by any of the common reactions which coagulate and precipitate ordinary albumens. Every one is familiar with the fact that most common albumens will coagulate when heated, and that the albumen in milk will coagulate when treated with an acid. This latter is the common process of curdling. While the introduction of alkalies or strong mineral salts will at once precipitate these albumens in the form of white insoluble flakes it does not precipitate peptones.

It is not possible to get pepsin in an absolutely pure form. For commercial purposes, however, it may be secured with satisfactory purity. For these purposes it is extracted from the gastric mucous membrane of various animals, and then mixed with starch or sugar of milk and placed on the market. For laboratory experiments to show artificial gastric digestion the pepsin may be secured by taking the gastric mucous membrane of an animal, cutting it up very finely, and then extracting the pepsin from it with glycerine. These glycerine extracts if properly diluted and acidulated, readily digest proteids subjected to their action.

In the medical field pepsin in some form or other is frequently given to supplement the lack of this material in the stomach. In fact, the disease called by the too-general term dyspepsia, is, as the name indicates, frequently interpreted as a lack of the pepsin. *Dyspepsia* is, however, a pathological condition of the alimentary canal which is much more frequently not connected directly with the absence or presence of the pepsin, but is due to bacterial fermentation set up in the carbohydrates.

b.—Hydrochloric Acid. Gastric juice contains about two parts of free hydrochloric acid in a thousand. This fact is somewhat remarkable, as it is the only mineral acid in the body which occurs in a free condition. It is interesting to note in this connection that a certain mollusk of the genus *Dolium* secretes a salivary juice which contains beside the free hydrochloric acid free sulphuric acid. Of the exact manner in which this acid is formed in the stomach we know as yet nothing. There is a good deal of evidence pointing to the oxyntic cells of the stomach as the seat of the production, but the chemistry of it is still missing. The only reasonable explanation is that some of the neutral salts, like common salt, which is a combination of sodium and hydrochloric acid, are split into the free acid which then passes into the stomach, and the alkaline base which passes into the blood and which may account for the fact that the blood is normally alkaline even when no alkaline salts are found in the food.

c.—Rennet. In the making of cheese it was long an observed fact that sweet milk could be made to curdle quickly and effectively by adding to the milk a piece of the mucous membrane of a calf's stomach, or of some animal living upon a milky diet. There seems to be in the mucous membrane in question a ferment which has the power to coagulate milk. This ferment is called "rennet" or rennin. It has not been possible to get this rennet in a pure form, and so its composition is not known. It is

found in a much more concentrated form in the stomachs of sucking animals, for which reason these stomachs are used in the preparation of cheese, but in diluted and weaker forms it may be extracted from the stomachs of all mammals. No doubt the curdling of milk in the adult stomach is largely due to the presence of the acid in the stomach; but it can be shown that gastric juice may be perfectly neutral and still retain its power of curdling milk. The chemical nature of this process is not known. Possibly it is not very unlike the coagulation of blood, a fact which seems to gain credence in the observation that the milk will not clot or curdle unless lime salts are present. The action of the rennet, however, goes no further than the curdling of the milk. As soon as this is effected its action ceases, and by the pepsin the milk is converted into soluble peptones.

The mineral salts are the chlorides and phosphates of potassium, calcium, magnesium and iron, but as they figure in no integral way in gastric digestion we are not specially concerned with them here.

GASTRIC DIGESTION OF CARBOHYDRATES AND HYDROCARBONS.

Gastric juice exerts no digestive action upon the starches. The starches in a perfectly unaltered condition are passed into the intestine, and their digestion there turned over to the pancreas. Nor are the sugars affected, although there would be no special reason for a change in sugars, as all the sugars are soluble and dialyzable to begin with. Neither are the fats affected. Bits of tallow, lard or butter suffer no digestive changes in the stomach, save that by the general mixing of the stomach they are broken up into small bits. However, very frequently the fats are eaten not as pure fat, but in the form of droplets of fat enclosed in albuminous coverings. Thus in ordinary milk and cream, the butter is held in the form of minute droplets, each surrounded by a thin albuminous envelope. To get the butter in a pure form it is of course necessary to break

these envelopes and allow the contents to run together, a result which is easily brought about by the mechanical crushing of these envelopes in the familiar process of churning. It might, however, be brought about just as easily by adding bits of pepsin and acid to the cream and allowing this pepsin to digest away the albuminous coverings, and so permit the buttery droplets to run together.

Such a condition of things we meet with in the stomach. Fats taken in the form of such droplets, as in milk or cream, have their albuminous covering digested away by the gastric juice, and the fatty contents liberated. Or when fatty meat is taken, the connective tissue covering as well as the coverings of the fatty cells are digested away and the contained fat set free. But this action is clearly an action on the albumens and albuminoids, and has really nothing to do with the digestion of the fats themselves.

Gastric juice will digest the albuminoids. Bits of white fibrous tissue, or ordinary connective tissue or cartilage are disintegrated and the gelatine extracted.

SUMMARY.

When the process of gastric digestion, after a period of four or five hours comes to an end, we find the following state of things:

First. The change from the starch to the sugars begun by the ptyalin in the mouth is temporarily arrested in the acid juice of the stomach.

Second. A large part of the proteids have been taken through several intermediate stages and been finally changed into dialyzable peptones.

Third. Starches have in no wise been affected.

Fourth. Pure fats have not been affected at all, but fats when surrounded with albuminous envelopes, as in the case of milk or cream, or of fat meat, have had these albuminous coverings digested away, and been thus liberated.

Fifth. Sugars have not been acted upon.

Sixth. The milk has been curdled by the acid of the stomach and by the rennin, and more or less fully converted into peptones by the pepsin.

Seventh. A number of mineral salts which we take into the body daily, as ashy ingredients of our foods, have been dissolved by the acid of the stomach and so enabled to pass into the blood. In this way much of the mineral matter for the body, which would be perfectly insoluble in water is dissolved, and so rendered suitable for the body's purposes. With the gastric contents in this condition the pyloric sphincter from time to time relaxes, and the now fairly semi-liquid food is passed into the duodenum to be further subjected to the action of the succeeding digestive agents.

The explanation why the stomach does not digest itself is given by some as due to the resistance of its epithelial lining, by means of which it is protected from the digestive action of the juice, the keratin of the epithelium cells being indigestible. Others find the explanation in the circulating alkaline blood through the walls, by means of which the walls themselves can never become acid, and so never susceptible to the action of the gastric juice. It is interesting to note that ulcerations of the mucous membrane become susceptible to self-digestion, which may finally lead to the formation of holes through the gastric wall.

3.—*The Pancreatic Juice.* Fresh pancreatic juice is a clear, viscid, alkaline, rapidly putrefying liquid, slightly heavier than water, coagulating completely when subjected to boiling. Its composition is as follows:

First, albumens. Just what the exact nature of these albumens is has not yet been determined. They coagulate easily upon being boiled. Whether, in fact, they have any digestive action at all is still questionable.

Second, several ferments or enzymes. These enzymes are trypsin, amylopsin, and steapsin.

Third, a number of mineral salts, mostly sodium salts.

Fourth, water.

About ninety per cent. of the pancreatic juice is water. Dissolved in it are the mineral salts, to which the alkalinity of this juice is due, for unlike the gastric juice, the ferments of the pancreatic juice can act in an alkaline medium only, and not in an acid one. The pre-eminence of pancreatic juice as a digestive agent, exceeding very much that of the pepsin or ptyalin, is due to the presence of the three ferments named, trypsin amylopsin and steapsin.

Trypsin. Trypsin is a very powerful ferment changing with great energy proteids into peptones. It is this ferment which acts upon all those proteids left unacted upon by the stomach, and upon all of the intermediate stages left incomplete by the pepsin. Here, too, the change from the proteids to the peptones is not a simple and direct one, there being a number of intervening stages called here, also, proteoses, the final resulting stage, however, being peptone in no essential way distinguishable from the peptone made by the stomach. The powerful digestive action of trypsin is shown in the fact that some of the peptone is disintegrated still further into two substances called *leucin* and *tyrosin*, substances which the chemist may readily detect where pancreatic digestion is going on, but the physiological significance of which we are at present not at all able to understand. The peptones are, of course, the source of the nitrogenous foods of the body, but why some of the peptones should be broken up, that is, digested still further into bodies like leucin and tyrosin, bodies which seem to play no part as foods, is not at all clear. The trypsin is also able to digest any albuminoids which may have escaped digestion in the stomach.

Amylopsin. Amylopsin is a ferment of the pancreatic juice identical with the ptyalin of the saliva, and like this ptyalin possesses the property of changing starch into maltose. The pancreas is called by the Germans the "Abdominal Salivary Gland," no doubt because of the identity of its action on the starches, with the salivary glands. The

starches which are left entirely unacted upon in the stomach, are now subjected anew to ferments. The ptyalin of the saliva continues its action, while the amyllopsin added from the pancreatic juice soon completes the digestion of the starches and effects their entire change into soluble maltose. There is no good reason for calling the ptyalin of the pancreatic juice by a new name unless it be that the term "amyllopsin" indicate the source from which the ptyalin is derived.

Steapsin. Steapsin is a ferment of the pancreatic juice which has the property of splitting fats into a fatty acid and glycerine. The chemical nature of this change is the same as that of ptyalin. Under the action of the steapsin the fat is made to combine with more water and the resulting molecule is then split up into glycerine and a free fatty acid. It has not been possible to isolate this steapsin, and so we know at present nothing about its chemical nature. The splitting up of fats into a fatty acid and glycerine is, however, a very common occurrence and familiar to every one. When butter becomes old, it acquires an offensive, rank odor. This is due to the fact that the butter, which is a pure fat, has been split, in this case by an organic ferment, into an acid called butyric acid, and glycerine. It is the butyric acid which has the disagreeable odor. The same thing is true of other fats. Exposed for a long time they become, as we say, strong and rank, the explanation of which is found in the fact that these pure fats have been split into a fatty acid, hence their odor, and glycerine. These fatty acids may be made to combine easily with some form of alkali and so soap produced. Soap is, in fact, nothing but the combination of a fatty acid with some suitable alkali. In the once very common manufacture of household soap, the rank fats were boiled in a kettle with some form of lye, the resulting combination being soap.

The physiological value of the ferment, steapsin, is found not immediately in the fact that it splits these fats up into glycerine and fatty acid, but in the succeeding fact, that

the fatty acids so produced in the intestine, unite with some of the alkaline ingredients present and form soap. It can be easily shown in a chemical laboratory that the formation of soap is practically impossible when a perfectly pure fat is used. Traces of a fatty acid must be present to help the process along. In the intestine this fatty acid is produced by the steapsin and so the formation of soap rendered possible and simple.

The question then at once arises, what the physiological value of soap is in the intestine. In the first place, soap is soluble and dialyzable, while ordinary fat is not very dialyzable, and so if the fats are changed into soap it will make quite easy the transfer of these substances into the blood. The same is true of glycerine also, which is always formed when the fats split up into a fatty acid.

The main purpose, however, of the soap is probably to aid in the emulsification of the remaining fats. It was pointed out in discussing the action of the gastric juice on fats that all the fats were liberated. In the intestine they are prepared for absorption. A small per cent. of them, as just indicated, is changed into fatty acid, and then into soap. The rest is emulsified. An emulsification of an oil or fat is effected when the oil in question is shaken up very thoroughly with some liquid, so that the two seem to have been intimately mixed and the fat is prevented from running together by being suspended in tiny droplets surrounded by a thin envelope to prevent them reuniting. Thus, cream is an emulsion of butter, the tiny particles of butter being surrounded by an albuminous covering and so prevented from running together. Lather is an emulsion of air and soap-suds. The significance of the emulsification of the fats lies in the fact that the bits of fat in the intestine are separated into very tiny particles small enough to pass through the walls of the alimentary canal in a manner to be described in the following chapter. In large chunks or bits this would be impossible, but reduced to

tinest globules the absorbing cells of the intestine are able to manage them properly.

In the emulsion of these fats the soap formed in the intestine seems to figure directly. Probably the tiny little droplets of fat are surrounded by thin envelopes of soap and so prevented from reuniting. That soap is pre-eminently fitted in making an emulsion is evident as soon as we think of soap-suds and lather. We have, therefore, to picture to ourselves the way in which the fat is acted upon about as follows: The liberated fats of the stomach reach the intestine, meet some of the steapsin ferment, and are then partly split into a fatty acid and glycerine. The fatty acid at once unites with some alkaline ingredient of the pancreatic juice or bile and soap is formed. This soap by means of the peristaltic motions of the intestine is shaken up with the remaining fats and emulsifies them, so getting them ready for absorption. That some of the fats in the form of soap, finally reach the blood, is probable, but the physiological value of this soap is in its emulsifying action upon the remaining and larger portion of the fats.

Summary. What, then, is the final state of things after the process of pancreatic digestion has continued for several hours?

Of course while the pancreatic digestion has been going on the bile has been poured into the intestine and has produced some effects, and the intestinal juice has also been acting. But leaving this out of consideration for the present the final state of things is about as follows:

First: All the proteids which the stomach has left untouched and all those proteids which the stomach has only partially changed into peptones, have been completely changed into peptones by the trypsin.

Second: Any albuminoids that may have escaped digestion in the stomach are dissolved and the gelatine extracted.

Third: All the starches are finally changed into maltose by the renewed action of the ptyalin of the saliva, but mainly by that of the amylopsin ferment of the pancreas.

Fourth: The fats have been doubly affected. A small part has been saponified, that is, made into soap by the steapsin, and the remainder has been emulsified. Sugars have been left untouched. It will be seen, therefore, that at this stage of digestion all the proteids, all the fats, all the starches are ready for absorption. The sugars alone have escaped any action.

4.—*The Bile.* The liver plays but a very small part in the process of digestion, and the bile which it pours into the duodenum must not be classed in importance along with the digestive agents so far considered. The liver is an exceedingly important organ when the phenomena of nutrition and metabolism in the body are considered, but plays a minor role in digestion. In fact, bile is largely an excretory product. It digests nothing itself, although incidentally it does serve several digestive purposes. Human bile is of a golden color, exceedingly bitter, neutral in its re-action, and emitting a peculiar characteristic odor. It is a little heavier than water. When the bile is taken from the gall-bladder it contains a mucin-like substance which was added to it in its passage through the bile-ducts and in its stay in the gall-bladder. This was formerly designated as ordinary mucin, but its re-actions are not those of ordinary mucin, and it is probably a slightly different product. However, in a general way we may still speak of it as mucin. While the color is usually a golden yellow it changes its color so readily as to appear sometimes a greenish yellow, sometimes a greenish brown, still other times pure green or brown. These changes in color are brought about by different degrees of oxidation of the bile pigments.

The quantity of bile secreted during a day for average persons is from 600 to 900 cubic centimeters. In animals which have no gall-bladder the bile is poured into the intestine in a continuous stream, but in those possessing a

gall-bladder the secretion is allowed to accumulate in that, from which in turn it is ejected in spurts at stated periods into the duodenum. The average composition of bile includes the following substances in 1,000 parts:

Water about 900 parts,
Mucin about 25 parts,
Bile salts about 30 parts,
Cholesterin about 2 parts,
Mineral salts about 10 parts,

Also traces of soap, fats, and lecithin. In addition to these there are traces of bile pigments, to which the color of the bile is due. The large amount of water serves, of course, as the fluid medium in which all the other substances are dissolved and by which they are carried.

The Bile Salts. The most important constituents of the bile are the bile salts. These are the sodium salts of two peculiar acids called *glychocholic* acid and *taurocholic* acid. It would be out of place here to go into the chemistry of these organic acids. It may, however, be of interest to call attention to the point that the taurocholic acid contains sulphur. These two acids are not found in the blood, but are made by the cells of the liver and by these poured into the bile-ducts. They are probably substances which have resulted from the breaking down of some proteid or albuminoid substance in the process of metabolism, and are primarily intended for removal from the body. It is interesting, however, to note that these bile salts are re-digested in the intestine, and are almost wholly re-absorbed into the system. These bile salts have some important functions; in fact, they are considered indispensable, and are treated by some physiologists as by no means mere excretions, but special secretions intended for specific purposes. In the first place these bile salts hold in solution the cholesterin of the bile. *Cholesterin* is insoluble in the bile as soon as the bile salts are removed. It is a non-nitrogenous substance very widely distributed in the body, being found especially abundant in the white matter of nerve tissues. In

small amounts, however, it is found in all animal and plant cells. This cholesterin is, therefore, probably not formed in the liver, but is merely eliminated by the liver cells from the blood, and poured into the bile secretion to be removed from the body. As far as we know now it is a pure excretion, the accumulation of which in the blood would prove dangerous. It is sometimes precipitated in the bile-ducts or gall-bladder and so gives rise to the formation of gall stones, which may in many cases consist of pure cholesterin, the removal of which from the gall-bladder or bile-ducts is frequently a matter of the severest pain, and oftentimes results fatally. In the second place these bile acids seem to facilitate the absorption of fats from the intestine, and to help materially in the emulsion of the fats, a point to be discussed later. The exceedingly bitter taste of bile is due to these organic bile salts.

The Bile Pigments. The bile owes its color to the presence of small amounts of substances called bile pigments. These pigments, according to the animals from which they are taken, are of two kinds, the golden *bilirubin* or the greenish *biliverdin*. The bilirubin is present in fresh human bile and occurs normally in the bile of most carnivora. On the other hand the bile pigments in the case of most herbivorous animals is the greenish biliverdin. Biliverdin and bilirubin are practically the same, one being only a slight oxidation product of the other, and it is very easy by this means to change one into the other. This fact is made use of in detecting the presence of bile pigments. If to some human bile in a test-tube a little fuming nitric acid be added, the acid being heavier will sink to the bottom, the bile being in contact with it above. At this point of contact the bilirubin undergoes a succession of color changes, through green, blue and violet, to yellow. This play of colors is due to the successive stages of oxidation of the bile pigments. The bilirubin is in the first stage changed to green, a change due to the formation of biliverdin. In

such a test tube the colors will arrange themselves one above the other in the order indicated, the most advanced stage of oxidation being of course next to the nitric acid, the least advanced stage of oxidation on top of the liquid. This characteristic re-action for the detection of bile pigments, familiar to all physiological laboratories, is called "Gmelin's re-action." It is a very sensitive one, and by means of it the presence of bile pigments has been detected in other liquids of the body, as for instance, the secretion from the kidneys. The bile pigments are of especial interest, because it is fairly well established that they are derived from hæmoglobin. When the red corpuscles break down in the circulation or disintegrate in the spleen or liver, the colored hæmoglobin is sent to the liver, and by the liver cells is converted into bilirubin or biliverdin. Hæmoglobin contains iron, but bilirubin and biliverdin are iron-free. This shows that the iron in the hæmoglobin must be retained in the liver, and possibly dropped back into the blood and sent to the marrow of the bones, to be used anew in the formation of fresh hæmoglobin. The amount, therefore, of bilirubin or biliverdin eliminated in the bile would give us a clue to the rapidity of corpuscular disintegration.

Bile is practically a watery solution of certain mineral salts which holds in solution goodly quantities of the organic bile salts. These organic bile salts hold in solution the cholesterin of the bile, and finally the bile pigments to which the color is due. In addition to these main constituents there are found in bile traces of fats and soaps, and a peculiar substance called lecithin, which is interesting because it is always found in nervous tissues and characterized by containing phosphorus. It is no doubt a mere disintegration product resulting from the activity of these tissues and sent to the bile merely to be removed as a waste product.

The reason for the presence of the fats and soaps in the bile is still missing.

The General Physiology of Bile. Our knowledge of the physiological value of bile still leaves much to be desired. Here more than with any other of the digestive agents our knowledge is fragmentary, and there is at present still no unanimity among leading physiologists as to the role which it plays. It seems probable, however, that the introduction of bile into the duodenum accomplishes the following results:

First. Bile is a slightly alkaline liquid, and as such poured in large quantities into the intestine it overcomes and destroys the acidity of the food as it comes from the stomach, and so prepares the material for the pancreatic digestion, which can only occur in an alkaline medium.

Second. Bile possesses to a considerable extent the property of emulsifying fats, and so materially assists the pancreatic juice in this function. This property of the bile is derived from the organic bile salts. It has been stated by some physiologists that bile has the property of splitting up pure fats into fatty acids, and so to assist the steapsin of the pancreatic juice in the formation of soaps. The emulsifying power of bile can be readily demonstrated by simply shaking up bile and oil, the result of which is a fairly stable emulsion.

Third. Bile is a mild stimulant and so starts the peristaltic actions of the intestine. It has been observed that a sudden gush of bile into the intestines will cause a peristaltic contraction to begin at that point and to creep slowly downward. It would, so to speak, be nature's laxative and the sluggishness of the intestines which follows the withholding of bile from them, as in various cases of biliousness, may be partly explained in this way. This stimulating effect of the bile is again due to the glychocholic and taurocholic acid salts.

Fourth. It is asserted by some physiologists, but strenuously denied by others, that bile helps in the absorption of fats. It was first stated that an animal membrane moistened with bile would allow fats to traverse it more easily,

but its validity is questioned. Just how it aids in the absorption of fats can not be told. The fact, however, remains that in an animal in which none of the bile is allowed to reach the intestine, which may be done easily by making a biliary fistula, the fat is not so readily absorbed from the intestine but accumulates there, and it may in large quantities be actually lost from the body. By turning the stream of bile back into the intestine and renewing the feeding of fats, at once larger quantities of the fats are absorbed and practically none are passed out.

We know that the absorption of fat is not a physical process, like the dialysis of sugar through the membrane, but is a physiological process in which the epithelial cells of the intestines actively pick up the fat, and it is probable that the helpful action of the bile in the absorption of fats is due to the direct stimulus which it exerts upon the epithelial cells. A stimulus possibly not unlike the one which it exerts upon the muscles of the intestine in arousing them to greater peristaltic activity.

Fifth. Bile is to a slight extent antiseptic, that is, it destroys, or more properly, retards putrefying changes. Such an antiseptic function has been assigned to it in the intestine. But before calling attention to this antiseptic influence it will be desirable to explain more in detail the reasons for the putrefying changes which occur here. Putrefaction is a process of disintegration, a kind of fermentation caused by bacteria. Such bacteria, however, are not dangerous ones; many are not only harmless, but actually helpful. Such helpful bacteria live in untold numbers normally and regularly in the human intestine. Here in the nutritious contents of the intestine they induce putrefactive changes, the important result of which is a softening and partial disintegration of the food. This softening and partial disintegration no doubt aids materially in their digestion, and without this disintegrating bacterial influence the efficiency of the digestive changes would be very materially impaired. Digestion itself is a sort of disintegra-

tion, a putrefying process, resulting not only in softening but actually in liquifying foods. It is customary in some portions of the globe to submit meats to a partial decomposition with a view of increasing its digestibility, and it is a common procedure in the manufacture of certain forms of cheese to allow them to proceed very far along in the process of decay in order to render them more digestible (some say palatable). Similar processes are constantly at work in the intestine, and so in a very short time, acted upon by untold numbers of these bacteria, putrefactive changes ensue and the food is hurried down the process of disintegration, and by the digestion finally turned into the proper dialyzable form. But however desirable such a softening may be it is absolutely necessary that this decay do not go beyond a certain stage. If it does, the food entirely disintegrates and ceases to have any nutritive value whatever. The point, therefore, is to so regulate and control these putrefactive changes that they shall not endanger the nutritive value of the foods, but shall stop at the point where the needs of digestion are accomplished. It is believed that the bile exerts such an influence. Thrown into the intestine in large amounts it acts as a slight antiseptic, checking, and so preventing an undue putrefaction. It is an observed fact that in animals whose bile is not allowed to flow into the intestine the decaying influences are much greater and putrefaction is excessive.

5.—*The Intestinal Juice.* As described in the chapter on the anatomy of the digestive system, the mucous membrane of the small intestine contains innumerable little glands called the crypts of Lieberkühn, the secretion from which is called the intestinal secretion or *succus entericus*. The glands of Brunner play no part in this secretion. They are, as was pointed out, merely escaped peptic glands, and so have no physiological value in the place where they are found. On account of the scantiness of the intestinal secretion, it is exceedingly difficult to get this fluid in even

practical purity. The best success in obtaining it, is made by an operation called a Thiry fistula, which consists in cutting out from the course of the intestine a loop, and then sewing the cut ends together again. In that way the food is again enabled to pass uninterruptedly along the intestine, save that the intestine has been shortened by the loop removed. The two cut ends of this loop are then sewed into the abdominal wall so as to connect with the exterior. The nerves and blood vessels of this cut loop are left untouched, and so when food passes along the intestine, secretion is also induced in this separated piece. This secretion is then collected and studied.

Such a fluid is light yellow and strongly alkaline. It possesses traces of albumin and is a little heavier than water. The alkalinity of this solution is due to the presence of a relatively large amount of sodium carbonate, but the general chemical constitution further than that is not known. In spite of statements by some physiologists to the contrary, there is no satisfactory evidence that the intestinal juice exerts any action whatever upon proteids or fats. Upon starches it has a slight effect. It contains a ferment much like the amylopsin of the pancreas which changes starch into sugar. However, on account of the scantiness of the intestinal juice this figures very little in ordinary digestion. The important use of the intestinal juice seems, however, to be its *action upon the sugars*. It contains a ferment capable of converting cane sugar, maltose and lactose into ordinary glucose or grape sugar. The sugars which occur regularly in our diet are ordinary cane sugar (the sugar of commerce), lactose (the sugar in sweet milk), and maltose, the sugar into which the starches eaten have been changed by the ptyalin and the amylopsin. None of these sugars are, however, found in the blood. The sugar in the blood is glucose or grape sugar, and it was long a question just how the sugars of the diet were changed into the sugar of the blood. This change occurs in the wall of the intestine under the action of the intestinal

juice. It is desirable to point out again that this change of the sugars does not occur in the contents of the intestine. The intestinal juice is too scanty to have much effect there, but occurs while the sugars, which are quite dialyzable, are in the act of passing through the intestinal wall. Here in the mucous membrane moistened with the intestinal juice, cane sugar, maltose and lactose are changed into glucose, and in that form all the carbohydrates eaten reach the blood.

GENERAL SUMMARY.

First. The proteids are not affected by the saliva. By the gastric juice they are more or less completely changed into peptones, and by the pancreatic juice the change from proteids into peptones is made complete, save that in the pancreatic digestion some of the peptones are digested still further into compounds called leucin and tyrosin.

Second. The albuminoids are not affected by the saliva but digested by the gastric juice, and the digestion when incomplete completed by the pancreatic juice.

Third. The starches are acted upon by the ptyalin of the saliva and partially changed into maltose. In the stomach all action upon the carbohydrates is suspended. In the intestine the ptyalin renews its action, but is aided by the amylopsin of the pancreatic juice and so all the starches are changed into maltose. This maltose, then, together with the cane sugar taken in the food and the lactose from the milk, is changed by the intestinal juice into glucose or grape sugar, in its passage through the walls.

Fourth. The fats are not acted upon by the saliva and are not directly affected by the gastric juice either except to be liberated when surrounded with albuminous envelopes, but in the intestines they are saponified by the steapsin and emulsified by the soap so produced, and by the bile.

Fifth. A number of mineral substances insoluble in water are dissolved in the free hydrochloric acid of the stomach, and in solution reach the blood. At the end of

the process of digestion, then, we have these resulting compounds: First, peptones; second, gelatine; third, glucose; fourth, soaps and emulsified fats. We have now to consider in what manner and by what routes these final products of digestion reach the tissues of the body.

CHAPTER XV.

ABSORPTION AND THE ROUTES OF FOOD.

In the preceding chapter the various changes were followed by which the undigested foods were transformed into substances which were able to dialyze through the alimentary wall into the blood. It was until recently believed that the absorption of all of the foods, with the possible exception of fat, was a mere physical process, and therefore animal membranes were taken to establish experimentally the details of the process. More recent work in this field proves conclusively that we have to do here with something more than mere physical osmosis; something more than mere filtration. We have to do here with living epithelium cells, which in a very active way, and according to physiological laws of their own, materially modify the simple physical process.

No doubt much of the food employed does pass into the blood by simple physical osmosis, but there is reason to believe that by far the largest proportion of the food absorbed is transferred into the system in consequence of the active participation of the living epithelium cells. This will explain why a dead piece of intestine has lost to so great an extent its power to absorb.

The exact way in which these living cells participate in this absorption we do not at present understand. Simple physical osmosis, however, may be easily studied on dead animal membranes. If, for instance, such a membrane be placed between two liquids of different composition, currents are at once set up through it tending to equalize the composition of the two fluids, the strength of the currents depending upon the dialyzing power of the substances dissolved. Thus, if on one side of such a membrane a solution of salt be placed; and on the other side a solution of

sugar, the salt will tend to flow toward the sugar side and the sugar toward the salt side. These currents will continue until finally the composition of both sides is the same. The ease, however, with which substances pass through membranes varies materially and is probably not the same with any two substances. Some, like the soluble mineral salts and sugars, dialyze easily, while others, such as albumins, dialyze with great difficulty. But not only do substances in solution pass through the membrane, but the water itself seeps through. Thus, if a solution of salt be placed on one side of an animal membrane and pure water on the other, not only will the salt seep across, but the water from the pure side will flow toward the salt side, and in this way by the dilution of the salt solution an equilibrium is finally established.

An example of osmosis can be readily illustrated on an ordinary hen's egg. Every one is familiar with the fact that a hen's egg which has been kept a day or two has at its blunt end an air space. This space is enclosed between the two walls of the shell membrane. If, now, the shell and that part of the membrane adhering to it be removed from above the air space, and the egg then partially immersed in water, osmotic currents will set in. Water will tend to flow into the egg and bits of salt and albumin out into the water. But as albumin is practically non-dialyzable, much more water will flow in than albumin out, and so the contents of the egg will increase in size and the partially collapsed shell membrane again be distended as it was in the fresh egg. If these osmotic currents are allowed to continue, the result will soon be that the shell membrane will be burst by the increased pressure caused by the water which the osmotic currents have carried into it.

When it was just stated that absorption in the alimentary canal has the vitality of the epithelium cells as an important factor, it was not intended to deny the prominent role played by osmotic currents. Thus, a draught of water readily passes into the blood, no doubt for the reason that

the blood is saltier than the pure water, and so the water in osmotic currents flows into the blood. On the other hand, if sufficient salty water should have been drunk and the contents of the alimentary canal become saltier than the blood, water would run from the blood into the alimentary canal and the thirst be exaggerated. These osmotic currents explain the physiological action of certain salts which are sometimes prescribed by the physician. Such mineral salts, usually Epsom salts, increase the saltiness in the intestine so greatly that currents of water from the blood pass into the intestine and thus produce the medicinal effects of that drug. On the other hand, if these salts were injected into the blood and the saltiness of the blood thereby materially increased, larger quantities of water than usual would be absorbed from the intestine and so constipation produced or exaggerated.

To trace out in detail these processes of absorption, it may be desirable to treat of each class of foods separately. It is not necessary to call attention to the absorptive process in the various portions of the alimentary canal, because experiments conclusively show that practically all the absorption occurs in the small intestine. It seems a little remarkable at first to find that practically no absorption at all occurs in the stomach. Experiments have been made over and over again to show that dialyzable substances, even water itself, are absorbed in very small quantities indeed from the stomach. As a digestive agent it has an important role, but as an absorbing organ it figures little indeed. Experiments have been tried on animals by injecting water into the stomach and keeping it there an hour or more, and then determining how much of it had been absorbed in the meantime. Such experiments show that but a trifling amount is thus absorbed. We have to imagine, therefore, that nearly all of the liquids and dialyzable substances which we take into the stomach and which seem to reach the blood so quickly are at once passed by the stomach into the duodenum and absorbed from that place. Even alcohol

is not readily absorbed. Traces of peptones and sugars, and possibly salts may be absorbed when one speaks mathematically, but for practical physiological purposes we have to turn to the small intestine for this function.

THE ABSORPTION OF THE PEPTONES.

It will be remembered that the various proteids taken in the body are by the digestive changes of the pepsin and trypsin finally converted into peptones, leaving out of consideration for the present small bits of peptones which have been disintegrated still further into leucin and tyrosin. These peptones are dialyzable, and so there seems at first no difficulty in understanding how they might enter the blood. But the difficulty presents itself quite seriously when it is recalled that peptones are not found in the blood anywhere, not even in the blood coming directly from the intestines. Evidently these peptones are changed after leaving the intestine and before reaching the blood. In fact peptones injected into the blood are poisonous. The blood coming from the intestines and carrying the absorbed food contains not a trace of peptone, but contains those albumens of the blood treated at length in the chapter on coagulation. It is, therefore, evident that the peptones were changed back into albumens in the act of passing through the intestinal walls. Experiments have been made to demonstrate this fact. Portions of fresh intestine have been removed from the body, filled with a solution of peptones, and the ends tied. This intestine was then immersed in a liquid containing not a trace of peptones and allowed to remain there until most of the peptones had disappeared in the intestine, but not a trace of peptone was found in the outside solution. Here it was present in the form of albumens. It would be interesting to know in what manner this change was effected. Is it due to the action of the epithelium cells? Is it a change brought about by the lymphatic tissue which is so plentiful in the walls of the intestine? These questions are, however, much more easily

asked than answered. The physiological significance of this change from peptones into the albumens of the blood is apparent. In the first place the peptones act as poisons in the blood. In the second place, being changed back into albumens they are robbed of their dialyzing power, and so there is prevented, possibly, the loss of the albumens in kidneys or glands, or even back again into the intestine, for peptones would dialyze into the intestine as easily as out of it.

THE ABSORPTION OF THE SUGARS.

No serious difficulty presents itself in understanding the absorption of the sugars. By the digestive actions of the ptyalin and the amylopsin, all the starches are changed to maltose, and finally by the action of the ferment in the intestinal juice all the various sugars taken in our diet, and the maltose derived from the starch are changed into dextrose or grape sugar in their passage through the abdominal wall. In the form of dextrose it reaches the blood, and by the portal circulation is carried to the liver, where it is affected in a manner soon to be described.

THE ABSORPTION OF THE FATS.

A greater difficulty presents itself in understanding the absorption of fats. That portion of the fats which is saponified and so rendered soluble (for soaps are soluble), will readily dialyze into the blood; but most of the fat is absorbed in its solid form; that is, in the form of finely emulsified droplets. A histological examination of the small intestine during fat-absorption shows droplets of fat in the epithelium cells, between them, and even under them, reaching into the lacteals. It is, of course, out of the question here to speak of physical osmosis. Droplets cannot filtrate. We are driven to the conclusion that it is the epithelium cells that line the intestine which actively pick them up; that is, ingest these droplets of fat into their bodies, pass them along through their protoplasm, and finally eject them again from the under side into the spaces

leading to the central lacteal. The droplets of fat are pushed in some inexplicable way through the epithelium cells towards the central lacteal. Possibly the epithelium cells pick up these droplets of fat much as the amœba picks up its food.

Additional factors in fat absorption are the white corpuscles, so plentifully distributed in the wall of the intestine. It is believed (and there is fairly good histological evidence for this belief) that the corpuscles wander in between the epithelium cells, ingest particles of fat like an amœba, and then wander back through the interstices of the tissue and drop their load of fat into the central lacteal, accomplishing this by disintegrating themselves and so lib-

Fig. 126.—SECTION OF A FROG'S INTESTINE TREATED WITH OSMIC ACID TO SHOW ABSORPTION OF FAT. (After Schäfer.)

l, lacteal; *c*, white corpuscles with contained fat granules; *ep*, intestinal epithelium; *str*, its striated border. The fat granules become smaller and smaller as they approach the lacteal.

erating their contained fat. On sections of the villi one may frequently see these white corpuscles with contained fat droplets in all positions ranging from between the epithelium cells to the central lacteal.

But all the fat suffers a peculiar change in its passage into the lacteal. In the intestine it was in the form of droplets. In the lacteal it is in the form of small particles as fine as the finest dust. But not only this mechanical change has occurred; there has been a chemical one. In the lacteal the fat is not present as butter, or lard, or tallow, forms in which it was taken in the food, but has been

changed into that peculiar form of fat characteristic of the animal which has eaten it. In the human body these dust particles of fat in the lacteal are now no longer butter and lard, but are human fat. As with so many other things we still have no knowledge of the manner in which this chemical change is effected. It may be in place to call attention to the fact that but little fat reaches the blood vessels. Practically all of it is carried by the lacteal. These vessels owe their name to the circumstance that after a meal they are usually filled with a white milky substance, the particles of fat in question. It was formerly believed that they absorbed all the food, and so were erroneously called absorbents. We know that the proteids, and the sugars, and the albumens are carried by the portal circulation to the liver.

It has been pointed out by some physiologists that possibly the involuntary muscular tissue found in the villi of the intestine produces a kind of contraction and expansion of each villus, and so the central lacteal is enabled to suck or force the fat into itself. These contractions of the villi, they hold, may be due to the stimulation caused by the bile, and in this way they explain the observed fact that bile seems to aid in the absorption of fats. Through these lacteals the fat is carried towards the thoracic duct, and by this poured into the left subclavian vein and so distributed by the circulation. The further changes which this fat undergoes will be discussed later.

The various salts, the water and the albuminoids in the form of gelatin, present no difficulties in their absorption and need not be further treated.

When finally all foods have been absorbed the following is the state of things:

First. The peptones changed back into the albumens are carried by the portal circulation to the liver.

Second. All the sugars changed into dextrose, are also carried by the portal circulation to the liver.

Third. The various salts and the water drop into the portal circulation largely; possibly, also, the soluble soaps, the glycerine and the albuminoids.

Fourth. The emulsified fats changed physically and chemically are carried by the lacteal and thoracic duct and dropped into the general circulation.

We have now to consider the physiological consequence of the transfer of these sugars and proteids to the liver before reaching the circulation at large.

THE GENERAL PHYSIOLOGY OF THE LIVER.

Some of the most important functions of the liver are in connection with the phenomena of general assimilation, and a discussion of the liver from this standpoint is reserved for the next chapter. We have to do in this connection only with the function of the liver as it affects the proteids and the carbohydrates in their passage through it into the body.

1.—*Glycogenic Function.* The most apparent function of the liver, and one of the most important as well, is its formation of *glycogen*. Glycogen resembles very much ordinary starch in many particulars, and is, in fact, frequently called animal starch. The liver forms this glycogen by changing the dextrose carried to it by the portal vein, into this compound. The point to the formation of this glycogen is the ability of the liver to store this substance in its cells and then to dole it out to the blood from time to time as it is needed. It would, of course, be practically impossible to store in an organ flushed with circulating blood dialyzable dextrose, but by changing the dextrose into an insoluble starch like glycogen it is easily retained.

The question might naturally arise concerning the necessity of storing any of the dextrose at all, and the objections to having all of it pass into the general circulation at once. These questions are readily answered. In the first place, quite a large amount of each meal is carbohydrate food, and if all this in the form of dextrose should be injected into the blood at once it would materially alter the composition of the blood and so lead to nutritive disturbances. The prime necessity of the blood is a practically uniform composition. In the second place, such largely

increased amounts of sugar in the blood would lead to diabetic results in the kidneys, for it is a commonly observed fact among physicians that an excess of sugars soon reveals itself by a sugary elimination from the kidneys. To avoid both of these dangers all the excess of sugar immediately after a meal is stored in the liver, and observations have been made on the human liver showing that the amount of glycogen so stored may reach 10 per cent. of the weight of that organ. Then during the interval between this meal and the following the liver doles out from time to time this glycogen, and so serves to maintain the uniform composition of the blood, adding the glycogen to it as fast as the sugar is used by its tissues. This addition to the blood is, however, not made in the glycogen itself, but this is converted back into dextrose in the liver, and in that form sent into the blood.

This glycogen may be readily detected. It may be seen microscopically in the liver cells in the form of clear lumps, which when treated with iodine give the chemical test for glycogen. Every chemical student is familiar with the fact that the usual reaction to detect the presence of starch is to treat the same with a solution of iodine. The starch will at once turn a very deep blue. Glycogen, however, does not turn a deep blue, but turns a wine red color, and in this way is easily detected. Unlike starch, too, it is somewhat soluble in water; more readily soluble in hot water, and by this means the glycogen may be readily extracted from minced liver.

It will be seen, therefore, that the liver is a kind of store-house, keeping a temporary reserve supply of glycogen to be used up in the intervals between meals. It is, to use a common figure, the pocket change to supply the daily needs of the tissue. It is quite interesting to note that the liver is not the only organ in the body which is thus able to take sugar out of the blood and store it up within itself as a reserve supply in the form of glycogen. Glycogen is found in other parts of the body. In white corpuscles, in

the placenta, but especially in the voluntary muscles. These voluntary muscles seem to be able to take some of the sugar out of the blood and store it up as glycogen within themselves as a reserve supply to fall back upon in times of activity. A muscle which has been working for some time loses all its glycogen. This reserve supply has been used by the muscle to build up its tissues. It is an attempt of these organs to have at their immediate disposal a certain reserve supply without being directly dependent upon the blood-stream at critical moments. The difference between the voluntary muscles and the liver, however, is that the reserve supply of glycogen in the muscles is intended merely for the use of the muscles, while the liver acts as a temporary storehouse for the entire system.

We have now followed the sugar into the liver, watched its change into the animal starch called glycogen, saw it stored in the liver cells and between meals doled out again to the blood as sugar. What further change this sugar suffers in the circulation and in the tissues to which it has been carried will be discussed in the chapter on nutrition.

2.—*The Albumens.* The albumens, too, are carried to the liver. One might be tempted at first to suppose that the sudden excess of albumens also is stored here, and then like the sugar is dropped back into the blood as necessity requires. But there is no place in the body where albumens can be stored. All the albumens available are in the circulating blood and lymph. Fats may be stored in fatty tissue and remain stored there for a long time. Sugars may be temporarily stored in the liver, but there is no storehouse for the albumens. These must drop into the general circulation at once. Here, however, the danger would present itself of increasing excessively the amount of albumens in the blood after a meal, and so producing nutritive disturbances here as well as with the sugars. Even a greater danger might ensue. The accumulating albumens of the blood might begin to be eliminated from

the kidneys and so induce Bright's Disease in some of its forms. The point, therefore, is to regulate in some way the amount of albumens in the blood to avoid this excess.

As the albumens cannot be stored but one alternative is left. They must be destroyed as albumens. This destruction takes place in the liver. Here the excess of the albumens is broken up; that is, disintegrated chemically into two main products. One product contains the nitrogen of the albumen and is the urea, which is then sent to the kidneys to be eliminated. The other part is a non-nitrogenous part, and is by the liver changed into fat or sugar, or both, and so made possible to be retained in the body. Whether this non-nitrogenous portion of the excess albumen is changed to sugar or to fat seems to depend to some extent upon the disposition of the animal in this matter. In breeding animals for fattening purposes special attention is paid to this fact, and those animals are selected which, as we say "fatten easily," and so a race finally comes to be, every member of which shows a tendency to convert all extra albumens into fat. In many instances, however, there is a tendency towards the formation of sugar, and so in spite of the richest diet but little headway is made in laying up fat. If this excess is turned into sugar in the liver it may, of course, at once be changed into glycogen and so stored for future purposes. If it is changed into fat it is dropped into the general circulation and distributed over the body.

We have thus far, then, found two sources of the glycogen in the liver. The first and main source, the sugars of the body; second, a derivative from the excess proteids. It does not seem possible that the fats are able in any way to be changed into the glycogen. This change of the proteids by their disintegration [or burning in the liver into urea and into glycogen, has a medical value in the fact that persons suffering with diabetes must not only avoid the carbohydrates, but must be equally careful not to take an excess of ordinary proteids lest the formation and loss of

the sugar continue. That portion of the proteids taken which is needed to maintain the proper composition of the blood is then without change of any kind allowed to pass through the liver and added to the general blood stream.

The thing in the albumens which makes them impossible to be stored is the nitrogen they contain. This nitrogen, as pointed out, is burned into the substance called "urea," is then allowed to drop back into the blood stream, and from this blood stream it is eliminated by the kidneys. The liver is therefore the seat of the urea formation. But it may be well at this place to point out that there is a second source from which the liver makes its urea. This second source is from the burned up tissues. Various products of tissue disintegration (and tissues are largely albuminous) reach the liver, and by the liver are burned into urea and then sent to the kidneys, as in the first case. The source of the urea is therefore a double one; one directly from the burning of the excessive albumens in the liver, the second from the burning of tissue wastes sent to the liver from all the organs of the body. The liver is, therefore, not only a storehouse, it is to some extent also a crematory for the nitrogenous wastes.

The final state of things is then as follows:

First. Definite amounts of the albumens have been allowed to pass through the liver and circulate in the blood.

Second. Quantities of dextrose or grape sugar are from time to time doled out from the reserve supply of glycogen in the liver and dropped into the blood stream.

Third. Into this blood stream are carried all the fats absorbed by the lacteals.

Fourth. In this blood, too, are the various mineral salts and the water taken in the foods.

The question which now presents itself is, in what manner are these nutritive factors of the blood used by the

tissues? How are the tissues able to grow by taking these substances? How are they able to derive energy and warmth from these sources? We are therefore ready to follow somewhat in detail the phenomena of assimilation in the tissues themselves.

CHAPTER XVI.

NUTRITION AND THE METABOLIC CHANGES IN THE TISSUES.

The scene of activity is now shifted from the alimentary system, from the liver, and even from the circulating blood and directed to the individual living cells wherever in the body they may occur. Here the most vital part in the history of the foods is played; it is here where the food is built into new tissues; it is here where the energies of the body are liberated.

A number of perplexing questions at once present themselves, the solution of which in every case is not yet forthcoming. Are all of the foods taken into the body built up into living tissue, or are some of them merely oxidized without ever becoming an integral part of the body? Is the energy derived by a direct oxidation of these foods, or is the energy a result of the disintegration of living material? When oxygen and its properties were first discovered by Priestly and Lavoisier, the conclusion seemed irresistible that the oxidations of the body occurred in the lungs. According to this view it was explained that the animal heat originated here, and was by the circulating blood carried over the body, and in this manner the necessary energy for bodily work distributed. It was, however, soon found that the blood coming from the lungs was not warmer than that going to the lungs, and so this view had to be abandoned. The seat of oxidation was later placed in the blood, then in the liver, then in other organs; but there is no question at all now but that the seat of oxidation is in the individual living cells in the various tissues all over the body. It is in the living tissues where the union of the foods and the oxygen occurs.

One of the most vital questions is whether these living cells can take some of the food out of the blood or lymph, and with the oxygen from the lungs produce an oxidation and so derive heat and energy for their own use. In other words, do these cells manipulate the foods like the fireman manipulates his coal? If so, how is the heat of such an oxidation transformed into the kind of energy needed, be it motion or be it chemical changes in secretion? Or may not the foods from the blood and the oxygen from the lungs be built up in the living cells into living tissues, and then by the burning up or chemical disintegration of this living matter the energy liberated? To use a not very close analogy, are the foods in the body burned like the coal in the furnace to heat the rest of the house, or are the foods like weather-boards, shingles, rafters and floors built into the structure of the house, and then by partial oxidation heat the house? Does the body maintain its equilibrium of temperature and derive its supply of energy out of its living supply, or from the external foods?

Of course there is no question at all as to what happens to some of the foods when the body is growing. Evidently they are built up into new tissues. The increase in weight and size from infancy to maturity is such a magical translation of dead food matter into living tissue. The question is here merely, are all the foods treated in this way, or may a part be used merely for fuel purposes. Unfortunately physiologists seem unable to agree on this point. There are not lacking some who maintain, and apparently with good evidence, that a large part of the food is directly oxidized in the tissues under the influence of the living cell without that food ever becoming an integral part of those cells. They maintain that a proportion of the food circulating in the blood circulates as fuel, while another part, not different in kind, however, is destined to be built up into tissue. They look upon the problem of nutrition as an instance of the carpenter who uses part of his lumber to construct his building and a second part of the lumber to burn

in his furnace to heat the building. According to this view the proteids or albumens of the blood are looked upon as the source of the new tissues, while the remaining albumens not so needed, and the fats and carbohydrates are used for direct oxidation purposes only.

Acknowledging that we are not yet able to answer definitely these intricate questions, there seems a good deal of probability that this view is not entirely correct. Repeated and careful experiments seem to lead to the conclusion that under normal circumstances all of the foods are first built into living tissue and then oxidized. The marked exception to this is in the case of excessive proteids taken into the body, which since they cannot be stored and must be eliminated, must be burned in the liver in the manner indicated in the preceding chapter. Here, of course, is a clear instance of a food directly oxidized by the living cells of the liver without ever becoming an integral part of that tissue. But it would hardly be right to look upon this excess of proteid as a food. Its very disintegration argues that it was not intended as a food but was eliminated as an injurious ingredient. The normal amount of proteids, however, of the blood, as well as the sugars and the fats, and of course the oxygen, must all be looked upon as tissue formers. But with the exception of certain special tissues in the body, such as the supporting tissues, all are essentially albuminous in their nature, and it seems at first difficult to understand how the fats and the sugars, which are not at all albuminous, containing no nitrogen whatever, could possibly be built into living tissues which are albuminous, that is, contain nitrogen.

In the case of the proteids this difficulty is absent. We must imagine a peculiar constructive chemical process going on in the living cell by means of which the proteid from the lymph, possibly with some salts, is combined with the oxygen and built up into some highly complex substance which we call protoplasm. Just as in the manufacture of gunpowder the charcoal and the oxygen contained

in the nitre, together with the other substances, are mixed together in such a way as to hold a large amount of latent energy. Gunpowder possesses enough oxygen within itself to burn itself up completely. In fact, it is this intra-molar oxidation which is the explosion. Gunpowder explodes because in every part of its substance there is enough oxygen present to burn up the other ingredients.

So we must imagine that the living cell is able in some at present entirely inexplicable way to take dead proteid and salts and to combine these with the oxygen from the lung in such a way that a kind of living gunpowder possessing much latent energy is produced. This view of the use of the oxygen from the lung changes completely the current notion. Usually we speak of the necessity of getting more oxygen in exercise in order that there may be a larger supply of this gas to burn up the tissues and so produce the energy. According to this view (and there is every probability that it is the correct one) the extra demand of the oxygen in exercise results from the necessity of building up new living tissue, of making new living gunpowder to replace that which has been used up in the exercise in question. The oxygen, then, is not the cause of the liberation of the energy; it is the result. Just as in a battle there would be greater demands for fresh supplies of gunpowder to replace the increased amounts being used up.

This constructive building up of proteids and oxygen into living matter does not present the difficulties which at once appear when we think of the sugars and the fats. The question arises, in what manner do these foods figure? In the first place it is well to remember that according to this view proteids alone can build up new tissue. Sugars and fats by themselves cannot do so. Of course such a thing is a chemical absurdity. We must therefore credit to the proteid every bit of new tissue that appears, and imagine its appearance in the manner just indicated.

The main characteristic of living tissue is its ability to do some kind of work. Life in this sense is energy,

either stored up or in action. When, now, these tissues are called upon for work of any kind the energy to accomplish this is derived from the chemical disintegration of a part of its living tissue, just as energy might be derived by the chemical disintegration of a bit of nitro-glycerine. We have therefore to look upon all manifestations of the energy in the body, be it muscle, or nerve, or gland, as a disintegration and burning up and dying of a part of this tissue. In such a chemical disintegration a good deal of energy is liberated, partly in heat to maintain the temperature of the tissues, or in the case of the muscles, in additional energy to contract them. The products of such a chemical disintegration are mainly as follows:

The carbon of the living tissue appears as carbon dioxide..... CO_2
 The hydrogen as water..... H_2O ,

And the nitrogen in the form of a compound closely related to urea.

The carbon dioxide is of course at once removed through the lungs in the manner explained at great length in the chapter on respiration. The water drops into the blood and is so lost track of, but the urea-like product, this remnant which contains the nitrogen of the living molecule, is not lost from the tissue, but is retained. The living cell which retains this nitrogenous remnant of the disintegration is able to use this remnant again to build up new living tissue. It is able to use the same nitrogen over again and needs only a new supply of carbon, hydrogen and oxygen to replace the amounts of these substances lost in the carbon dioxide and the water. This supply of carbon, hydrogen and oxygen it is able to take from either the fats or sugars of the blood and the oxygen constantly brought from the lungs. The living cell is able to re-combine the nitrogenous remnant with the carbon, oxygen and hydrogen derived from the sugars or fats, and an added amount of oxygen from the lungs into a new living tissue molecule having the same composition as the original. This molecule may again under nervous or other influences be dissociated and

so give rise to the liberation of new energy, carbon dioxide and water being the result, as in the first case, but the nitrogenous remnant being again saved and by combination with new fats or sugars and the oxygen from the lungs, be built for a second, a third, or fourth time into living tissue. If this view is correct it would explain why the loss in nitrogen does not vary with the work, a man resting eliminating from his body about as much as a man working.

When it is said that the nitrogenous remnant is saved, there is to be added that a small portion of this nitrogenous remnant, however, is lost; some possibly accidentally carried away by the circulating fluid, some possibly chemically unfit to be used again. It is this little loss, this wear and tear, which is sent to the liver and in the liver is burned into urea and then eliminated from the kidney. But this wear and tear may almost be as much in a resting person as in an active person, just as the wear and tear of an engine that is in proper use may not exceed the wear and tear of an engine standing idle on the sidetrack.

Some interesting experiments have been made showing that the loss of the nitrogen from the body is not at all proportional to the work done. Persons have ascended mountains and during the period of such exertions, as well as before and after, careful quantitative determinations were made of the amount of urea eliminated from the kidneys. It was found that even in such laborious work as mountain climbing the nitrogenous loss from the body was not proportionately larger, in fact hardly materially larger than the loss while resting. On the view just given of the manner in which the nitrogen is used over and over again this is readily understood.

The amount of carbon dioxide produced, and of course the water, is however, directly proportional to the amount of work done. At each chemical disintegration a certain amount of carbon, oxygen and hydrogen is lost, which must be replaced in the next constructive process by an equal amount of new material. Evidently, therefore, the amount

of this carbon, hydrogen and oxygen will be proportional to the amount of work done. This at once explains, too, the increased breathing of oxygen with increased exertion, and also explains the necessity for increased amounts of food with increased exertion.

But such an increase of foods need not at all be proteid, but may be fatty or carbohydrate. Of course a certain amount of proteid is absolutely indispensable, since proteid alone can replace the slight wear and tear just referred to. To eat more proteid food than necessary to replace this loss simply necessitates the body to eliminate it. In physiological terms we speak of a person or animal as being in a proteid equilibrium when the nitrogen taken in his foods equals in amount the nitrogen eliminated from the kidneys. In the same way we speak of a person as being in a carbon equilibrium when the carbon taken in his foods is equal to the carbon eliminated from his lungs. If more is eliminated than is taken in in any of these cases starvation and emaciation are the result. If more of these foods is taken than is needed one or both of two results may follow: Some of the surplus food, as for instance the fat, may be stored in the tissues for future use and so the person become fat, in the ordinary use of that term; or secondly, the nutritive equilibrium of that individual raised to a higher level. This needs a word of explanation. It is possible in a long continued diet to establish a nutritive equilibrium at an almost starvation diet. The tissues of the body will adjust themselves to the income, and finally establish an equilibrium at that level. This means that the losses will exactly balance the gains and the body will seem to hold its own. If, now, the amount and quality of the foods be suddenly increased, there is at first a tendency of the body to eliminate these extra foods, especially the proteids, but finally the tissues will adjust themselves to the new order of things, will use up increased quantities of food in their daily work, until finally a new nutritive equilibrium is established. As a simple analogy an illustration may be taken from the social

world: Persons are able to maintain a financial equilibrium with a small income, but there is no difficulty at all in soon adjusting one's self to an added income and so establishing an equilibrium on a higher level.

But this does not always mean that when a body is not losing in weight it is holding its own in the fullest sense. It is doing so at a low nutritive level, but it is still starvation, and the general beneficial effects that are recognizable in a community of well-fed people clearly argues the physiological necessity of establishing in a healthy body at least a medium, still better, a high nutritive equilibrium.

These metabolic changes and the final products have been fairly well determined only in the case of muscular tissue. What the final chemical changes are in glands ganglia and in nerve fibers, is still a wholly closed book. However, from a merely physical and chemical standpoint the energies liberated by the muscles are by far the bulk of the body's whole expenditure.

By way of summary, then, we have to ascribe to the main classes of foods these nutritive values:

First. Proteids.—(a) All new tissue, that is, all living tissue which has not replaced the old, but is an actual addition, can only be built up from the proteids of the blood and lymph. Hence the somewhat larger proportion of proteids needed in the diet of animals which are in the growing period. (b) Excesses of proteids are broken up in the liver into a non-nitrogenous portion which may appear there as sugar or as fat, and a nitrogenous portion appearing as urea. The sugar or fat so produced from these proteids will then figure just as the other fats and sugars.

Second. The Albuminoids. These do not figure in an important way, and it is highly improbable that the nitrogen which they contain can in any material way be utilized like the nitrogen of proteids. Probably the albuminoids figure in the same role as the sugars and the fats.

Third. The Sugars and the Fats. These are the non-nitrogenous foods, but in the tissues these non-nitrogenous

foods are combined under the influences of the living cell with the nitrogenous remnant there of a previous disintegration, and so built up into living tissue. These sugars and fats supply that part of the food which in the disintegration of the living tissue is lost; they supply the carbon and the hydrogen. As these, therefore, cannot be used a second time, new amounts of sugars or fats must be taken to replace them. In this way the consumption of sugars and fats of the blood must be proportional to the amount of work done. Of course, if sugars and fats are not given in sufficient amounts, or are excluded altogether, the body is able to derive this oxygen, carbon and hydrogen from proteids alone. But then this great excess of proteid must be first dissociated in the liver, and so sugar or fat produced, and these be the immediate foods of the tissues. Carnivorous animals can live upon a diet of meat alone, and in such cases the quantity of meat will, to a large extent, be proportional to the work done. But the proportion is not in the nitrogen which it contains, but in the carbon and hydrogen which are needed.

An ideal physiological diet, therefore, is one that contains enough proteid to replace the wear and tear of the body on a high nutritive equilibrium, and then has the carbohydrates and fats as the sources from which the carbon and hydrogen are derived. Increased work, therefore, would demand not primarily an increase in the proteids, but would at once demand a proportional increase in the fats and sugars.

It was pointed out that a little of the nitrogenous remnant which results from the disintegration of a part of the living cell is lost, possibly accidentally, more probably because it is no longer fit to be used. This nitrogenous remnant no longer retained by the cell is dropped into the blood and is by the blood carried to the liver. This substance appears in several different stages of oxidation and is known to the chemist as *kreatin* or *kreatinin*. This kreatin arising in the tissues of the body and carried to the liver by the

blood is in the liver burned still further into urea, and then sent to the kidneys to be eliminated.

We have thus seen two sources of urea in the body, one derived from the immediate burning up of the excess proteids in the liver, the other derived from the kreatin and similar compounds of the tissue destruction. But the formation of this urea occurs in both cases in the liver. The kidneys take no part whatever in the production of this substance, but are concerned wholly and only with its elimination. When the diet is naturally rich in the proteids, and when, therefore, increased amounts of these urea-like substances appear in the blood, the kidneys are frequently unable to eliminate this from the body as rapidly as it is being formed, and so there is a tendency towards the accumulation of uric compounds in various parts of the body, especially at the joints, producing the somewhat aristocratic disease called the "gout." These uric poisons in the blood serve to irritate the tissues and so produce quite abnormal conditions. The remedy is, of course, the removal of these poisonous salts from the blood. One of the best agents in the physician's hand is some form of salicylic acid, in which these salts are soluble, and which when taken into the blood tends to dissolve them out of the tissues. Along with such tendencies to gout the increased demands made on the kidneys may finally result in the impairment of their energies, and so Bright's Disease be induced, a disease alarmingly frequent among persons addicted to a luxurious table.

Whether the familiar rheumatism is due to an accumulation of metabolic products in the blood is still unsettled. Some look upon it as a disease due to germs, others as a cold affecting nerve centers, and by still others, and possibly most, as a result of the accumulation of lactic acid in the blood. It has even been claimed by one observer that it was possible to produce rheumatism artificially by an injection of lactic acid into the system.

THE INTER-RELATION OF THE FATS AND CARBOHYDRATES.

It was of course long known that a proteid diet might result in the fattening of an animal; also that proteids might give rise to sugar. It has been an important but difficult question whether the carbohydrates ever give rise to fats; whether a sugary diet leads directly to the production of fatty tissues. Until very recently it was almost universally held that the carbohydrates could not form fats in the body, and that the fattening resulting from adding a carbohydrate food was due merely to the saving of fats, these being substituted for them. Just as on the dinner table it might be possible to produce an accumulation of bread by having plenty of pie. Of late, however, investigations have been made which seem to show that carbohydrates in the body may be changed into fats and so stored. Attention is here called to this claim since it is possible that future observations may establish its correctness; but the point remains that in spite of these claims there is much evidence that fats are never the direct result of the sugars or the sugars of the fats, and that there is in no way a direct causal relation between them.

No attention has been given to the nutritive importance of the water and the salts. It has not been deemed necessary to go into detail here. Water is the general solvent of the body and the medium in which the cells live, and as such is absolutely indispensable. The salts, too, are necessary parts, frequently being directly used in the formation of tissues, as in the case of bones and red corpuscles, or directly serving an intermediate function in the process of osmosis or solution.

The attempt has been made in the chapter to try to picture the phenomena which take place in the individual living cells while these cells are in growth or action. We have now to determine somewhat more quantitatively the results of the energy so derived, the purposes of this energy, especially that of the temperature of the body, and finally the manner in which this temperature is maintained at a steady and fixed level under normal conditions.

CHAPTER XVII.

THE MAINTENANCE OF THE ANIMAL HEAT.

As long as the body is alive heat is being produced in it. Even a muscle that may be showing not a bit of contraction is nevertheless developing a certain amount of heat. Heat is a constant product of the transformation of energy in the body. The most noteworthy fact in examining this heat-production is its steady maintenance under normal conditions. Thus the temperature of an average adult is about $37\frac{1}{10}^{\circ}\text{C.}$, and this temperature is maintained through summer, through winter, and through all of the vicissitudes of every-day life with almost mathematical exactness.

Animals which have such a constant temperature are spoken of as *homothermous*; that is, as the etymology of the word shows, of constant temperature. Animals possessing a constant temperature have one which is usually above the temperature of their surroundings. They are warm-blooded. This is true of nearly all the higher animals. As we descend the scale, however, this condition changes, and we find the temperature of the lower animals determined almost wholly by their immediate environment. Their temperature rises or sinks with the temperature of their surroundings. Such animals are called *poikilothermous*; that is, of several temperatures. More frequently such animals are spoken of as cold-blooded animals, but it not infrequently happens that the temperature of such a cold-blooded animal may even be higher than that of a warm-blooded animal, provided the medium in which it lives rises above that temperature. Examples of cold-blooded animals are the fishes, amphibians and reptiles.

VARIATIONS IN TEMPERATURE.

The temperature of warm-blooded animals is not absolutely constant by any means. Thus, mammals which go into a winter sleep, hibernate, as we say, have their temperature sink several degrees, in this way approaching somewhat the cold-blooded animals. The advantage of being able to lie in this protracted sleep at a somewhat reduced bodily temperature is, of course, very evident when we remember the saving of tissue on this account. Some of the mammals show a transition to the lower classes in their temperature. Thus, the temperature of the monotremes, a group of animals to which the Duck-bill belongs, is normally no higher than 30°C .

There are also differences in the temperatures of different classes of warm-blooded animals. Thus, as a rule, the temperature of larger animals is less than that of smaller ones. In the case of birds the highest temperature is reached, running up as high as from 40° to 45°C . This in the human body would be a fever-heat and would in all probability prove fatal. This relatively much higher temperature in birds no doubt facilitates muscular contraction, and may be easily explained by relating it to the flight of birds.

But differences in temperature may occur in the same individual. Thus, there are differences on account of age. The temperature of an infant is usually the highest, being about $37^{9/10}^{\circ}\text{C}$. From this it sinks to about $37^{1/10}^{\circ}$, which is the temperature of active adult life. As age advances the temperature sinks still further, and at seventy is about $36^{8/10}^{\circ}$. However, in real old age it begins to rise again and frequently reaches $37^{4/10}^{\circ}$, almost the temperature of an infant. Numerous observations seem to show, too, that the temperature in females is slightly lower than in males.

There are even differences in temperature in the different regions of the same body, the highest temperature being reached in the liver and the internal glands, where it is not infrequently and normally from 38° to 39°C . The

lowest temperature is in the most exposed portions of the skin, such as the ear flaps, where on account of the excessive radiation of heat it may sink materially.

So far the variations in temperature have been normal variations. In addition, however, to these there occur the variations caused by external agents, either by the immediate surroundings or by pathological conditions within the system. The limits of temperature which may be so produced are considerable. One of the lowest temperatures recorded is $24\frac{6}{10}^{\circ}\text{C.}$, the temperature of a drunken man. The upper limits have been reached in fevers, when the temperature may rise from $37\frac{5}{10}^{\circ}$ to $41\frac{5}{10}^{\circ}\text{C.}$ Expressed in Fahrenheit degrees, the variations in temperature are from 76° , in the case of the drunkard, to 106° , in the case of fevers. Sometimes just before death temperatures from 110° to 113° have been recorded.

CONDITIONS AFFECTING THE TEMPERATURE.

The temperature is affected in a number of ways. The first and most apparent agency is, of course, the external environment. The temperature is higher on an average in summer than in winter. It is increased by taking hot things into the stomach, or by subjecting the whole body to a hot bath.

Secondly, the most usual agency affecting the temperature is the oxidation in the body. When this oxidation increases, as in the case of muscular work or exertions of any kind, the temperature increases along with it. It is the commonest experience of course that hard work makes one warm.

A third agency affecting the temperature is the blood-flow, especially through the skin. When the blood-vessels in the skin are dilated and much blood traverses it, it is there exposed to the radiating influences and is materially cooled. On the other hand, when the blood-vessels of the skin are contracted and little blood passes through there, much less opportunity is given for the heat to radiate from

the skin. This is one of the most efficient means the body has to maintain its temperature equilibrium.

One of the deceptive results of alcoholic drinks is the feeling of warmth experienced. This is due to the fact that under the action of the alcohol the blood-vessels of the skin have been dilated and the warm blood from the visceral organs traverses it, giving to the skin its sense of warmth. As a matter of fact, however, this exposes the warm blood to the exterior, and the result is a material loss of bodily temperature in spite of the deceptive feeling.

Fourth, the temperature may be materially affected by the administration of drugs. It may be increased by such drugs as atropine, strychnine, caffeine, and others; on the other hand, materially decreased by quinine, morphine, large doses of alcohol and others. These medicinal properties of drugs frequently enable the physician to increase, or more usually in cases of fevers, to decrease the temperature from a dangerously high point to the normal.

There is no question any more but that the temperature of the body may be directly affected by nerves carrying their impulses from nerve centers especially concerned in the regulation of the bodily heat. These thermogenic nerves, as they are called, are vital agents in the regulation of the temperature, a topic which naturally arises at this point.

THE REGULATION OF THE TEMPERATURE.

Any one who has ever had any practical experience in trying to maintain a uniform temperature in a room or house, even with the best modern heating appliances, realizes the great difficulty he has undertaken. In spite of the most improved modern contrivances and in spite of constant watching, the temperature of a large building will vacillate through many degrees in the course of a day. One is therefore naturally surprised to find the temperature of the body subjected in so many different ways to every change in external conditions remain so constant, and the

question naturally arises, in what manner the production of this heat is maintained and regulated so perfectly?

The agencies which figure in this regulation are of two kinds:

1.—*Artificial Agencies.* Such artificial agencies are, first, clothing and fuel; second, increased exercise. It is the commonest experience to maintain the temperature of the body on a cold day by increasing vigorously the amount of exercise. Third, with the approach of cold weather we change more or less consciously the kind and quantity of foods, eating in winter as a rule not only more food, but food of greater heat-producing quality. Fourth, as pointed out just above, we may regulate the temperature to some extent by the administration of drugs, a regulation frequently called in in the reduction of temperatures in feverish conditions.

2.—*Natural Agencies.* The second group of agencies are those which might be designated as the natural ones; that is, agencies which come into play without our conscious intervention. These are, first, an increased activity of the heart and lungs in cold weather; second, contraction or relaxation of the capillaries of the skin; third, the perspiration of the skin, in the evaporation of which much heat may be eliminated from the body; fourth, a natural increased hunger; fifth, involuntary movements, such as the familiar shivering and chattering of teeth which follow undue exposure to cold; sixth, the thermogenic nerves.

THERMOGENIC NERVES.

It has now been settled beyond a matter of question that there are nerves in the body which are concerned directly with the production of heat. The centers from which these thermogenic nerves arise, lie probably in the spinal cord. These centers in the spinal cord may, however, be stimulated or inhibited by higher centers lying in the brain and medulla. Repeated experiments in this direction seem

to indicate that there are *heat-accelerator-centers* as well as *heat-inhibitory-centers*. These have been localized especially in the region of the floor of the brain occupied by the corpora striata. These centers in a reflex way stimulate the centers of the spinal cord to greater heat production, or inhibit them and so lessen the heat production. In this way it is believed the heat equilibrium is so successfully maintained.

Under normal conditions these heat centers are adjusted or set for a temperature of $37\frac{1}{10}^{\circ}\text{C.}$, but in abnormal conditions, such as fevers, they may become set or adjusted for a higher temperature. Experiments on the lower animals show that they may also be set for temperatures beneath the normal. It would be interesting to know just what it is in the case of fevers which changes the readjustment of these centers from the normal point to the fever point. But this information is not at hand. Possibly some of the poisons of the disease may act as an irritant upon these centers and thus disturb the equilibrium. Unfortunately, too, we have no knowledge yet in what specific manner such drugs as quinine act in the reduction of these fever temperatures.

It is, of course, not necessary to say that these thermogenic nerves running to the various tissues in the body are not anatomically distinguishable, but that the existence of such centers and such nerves is based wholly upon physiological grounds.

QUANTITATIVE DETERMINATIONS OF THE SOURCE AND EXPENDITURE OF HEAT.

Heat may be measured just as corn or wheat. The unit of heat measure is called the *calorie*. A calorie of heat is the amount of heat necessary to raise the temperature of one gram of water from zero degrees to one degree C. Or, defining it more generally, a calorie is the amount of heat required to raise one gram of water one degree C. As the amount of water in any given case can be accurately meas-

ured, and as the temperature may be equally accurately measured by thermometers, it is no specially difficult task to determine quantitatively the amount of heat under investigation. It is only necessary to take every precaution possible that none of the heat shall be lost by radiation or convection, but that all of it shall be transferred to a known quantity of water and so measured.

Such calorimetric measurements have been made for a number of substances and the quantity of heat which they produce in burning accurately determined. Thus, one gram of carbon produces 8,080 calories; one gram of hydrogen, 34,460; one gram of proteids, 5,778; one gram of fat, 9,372, and one gram of sugar, 4,116 calories. One is at first astonished at this stupendous amount of heat. On the other hand, it explains easily how it is possible for a body to derive all its energy and heat from comparatively small amounts of proteids, fats and sugars.

To the older investigators it seemed impossible that the muscular energy and the large amount of heat lost from a living body should all be derived from the quantitatively small amount of food taken. This error was, however, due to their ignorance of the exact amount of heat which even such small portions of food produce when burned. That this amount of heat seems large is due to the fact that in the every day oxidations of the physical world such a very large proportion of the heat is entirely lost.

THE AMOUNT OF HEAT LOST BY THE BODY.

Experiments have been made to determine the amount of heat lost by the human body in a day. These were made by placing the person to be examined in a close-jacketed calorimeter so that all the heat which his body produced could be measured by measuring the temperature of the calorimeter and its water jacket. The experiment was, practically speaking, to confine an individual in a relatively small chamber, or still better, chest, out of which little if any heat could be lost by convection or radiation. The re-

sults of such experiments would, of course, vary largely according to the nature of the person experimented upon. In a person resting, about 2,500,000 calories are liberated in one day; or, measuring that in terms of the water which it would heat, it would be an amount of heat sufficient to raise 56 pounds of ice water to the boiling point. These figures are materially increased for a day of regular work. In a working day no less than 3,700,000 calories are produced. This amount of heat would be sufficient to raise 83 pounds of water from the freezing to the boiling point.

These figures appear at first startling and it seems almost incredible that in one day, losses so large should occur. However, the fact that this heat is being continually radiated little by little explains this popular error. It is further interesting to know that the amount of heat lost by the entire body, plus the amount of energy lost in muscular motion, is about the same as the food taken during the day would give if directly oxidized outside of the body. This agreement between the theoretical amount of heat in the foods taken and the actual amount of heat lost in the body when that body is in a state of nutritive equilibrium proves without further question the source of all the energy of the body and the absurdity of calling in any so-called vital force to explain an apparent discrepancy.

The interesting question at once follows, in what manner this large amount of heat is daily lost from the body. Here, too, fairly accurate experiments help us out and show about the following distribution of the loss:

73	per cent.	direct radiation from the skin;
$14\frac{1}{2}$	"	evaporation of the perspiration from the skin;
$7\frac{2}{10}$	"	from the lungs;
$3\frac{5}{10}$	"	in the warmth of the expired air;
$1\frac{8}{10}$	"	lost in warming the excretions of the body.

It was pointed out in a previous chapter that of the available energy of the body about five-sixths is lost in heat, and only one-sixth utilized in actual muscular movements. This seems a very heavy proportion of loss of heat, and yet

when compared with the best engines it reveals that the body is very much superior indeed to them all. It is a very fine engine which can utilize one-eighth of its total energy, while most ordinary engines utilize no more than from one-tenth to one-twentieth. As the workings of the human body are subject to the same physical laws to which artificial engines are subject, it reveals the marked superiority of the body with reference to the energy at its disposal.

CHAPTER XVIII.

THE KIDNEYS, THE SKIN, AND THE GENERAL PHYSIOLOGY OF EXCRETION.

We have in the preceding chapters traced the foods through the various changes which they suffer in digestion; they have been followed through the intestinal walls into the blood or lymph streams. The changes which some of them undergo in the liver has been explained. We have seen them distributed in the blood and carried to the individual tissues. It was pointed out how at this place these foods were built up into living tissue, and how by the disintegration of this tissue the energy was produced. There now remains the final question concerning the nature of the waste products which result from this destruction and their final elimination from the body. This closing chapter in the history of the foods and tissues has therefore to do with the skin and the kidneys, the organs whose duty it is to take the final products of metabolism and remove them from the body.

THE KIDNEYS.

The kidneys are large, bean shaped organs lying on the back wall of the abdomen. They have a reddish characteristic color, but are usually more or less imbedded in connective or adipose tissue. The right and left kidneys do not lie at the same level, the difference in position between the two being often several inches. On account of their proximity to the back wall of the abdomen pains in the kidneys are usually referred to the small of the back. A large branch from the aorta, the renal artery, carries blood to each kidney, and a corresponding vein carries the returning blood to the ascending vena cava.

In its gross structure a kidney shows a connective tissue covering called the capsule. The kidney itself shows two

Fig. 127.—THE URINARY ORGANS FROM BEHIND. (Henle.)

A, aorta; Vc, vena cava; Ar, renal artery; Vr, renal vein; R, right kidney; U, ureter; Vu, bladder; Ua, urethra.

well marked areas, an outer one, reddish in appearance in a fresh specimen, and somewhat granular, called the *cor-*

tex, and an inner layer, whitish, revealing numerous glistening threads running towards the pelvis of the kidney. This second area is called the *medulla*. Between the cortex and the medulla the main blood-vessels of the kidney, both arteries and veins take their course. The interior of the kidney is hollow, and is called the *pelvis*. This pelvis connects with the ureter, by means of which duct the secretion is carried to the bladder. The medulla breaks in the pelvis into several (five to ten) pyramidal projections, called the *pyramids of Malpighi*. At the ends of these

Fig. 128.—DIAGRAMMATIC SECTION THROUGH PART OF KIDNEY PARALLEL TO TUBULES. (After Testut.)

a, papilla; *b*, medulla; *c*, cortex; 2, capsule; 3, tubules in medulla; 4, blood-vessels; 9, Malpighian corpuscles.

pyramids numerous uriniferous tubules open into the pelvis. The depressions between the pyramids are called the calyces.

All the points so far could easily be made out on a kidney without the use of any lens. For the final structure, the courses of the blood-vessels and the uriniferous tubules, recourse must be had to histological sections. For the sake of clearness it may be advisable to follow at first the course of the blood-vessels for some distance without paying attention to other structures, and then to turn to the uriniferous tubules.

1.—*The Circulation of Blood Through the Kidneys.* The renal artery enters the kidney at the hilum, and at once divides into numerous branches which run in every direction between the cortex and the medulla. From these main branches there arise smaller ones, which run directly outwards through the cortex to the capsule. These branches in turn divide into shorter branches, and these short branches soon terminate each in a small knot of blood-vessels, giving to the whole the appearance of a bunch of grapes. This network of blood-vessels is not really a capillary network. It is rather a nodule of small twisted arteries, with walls, however, sufficiently thin to allow the water and the salt of the circulating blood to pass out at this point somewhat readily. It is, therefore, well to bear in mind that the blood as it re-issues from this knot is still

Fig. 129.—A, SHOWING THE RELATIONS OF THE BLOOD-VESSELS AND URINIFEROUS TUBULE; B, A SINGLE GLOMERULUS FROM A PIG'S KIDNEY. (After Bowman and Ludwig.)

arterial. Upon leaving this knot, called a Malpighian corpuscle or glomerulus, the artery soon divides into capillar-

ies which surround in a very intricate way the uriniferous tubules lying in the cortex. It is at this point that the real secretion of the kidney takes place. After having passed from the capillaries it is gathered up in veinlets, which carry the blood back to the larger veins lying between the cortex and the medulla, which in turn unite at the hilum and leaving the kidney form the renal vein.

The circulation through the medulla is much simpler. Small arteries run inward from the main branches between the cortex and medulla, and divide up into capillaries which there surround the uriniferous tubules, while corresponding veins collect this blood and carry it back to the larger veins lying between the cortex and medulla, where it joins the regular venous stream. The circulation of the blood from the medulla is for nutritive purposes only, and no active secretion takes place here. The real physiology of the kidney belongs to the cortex.

2.—*The Course of the Uriniferous Tubule.* It was just pointed out that from the main arteries lying between the cortex and medulla smaller arteries ran directly outwards through the cortex towards the capsule; that these arteries gave off a number of lateral branches, and that these lateral branches soon ended in arterial knots called the Malpighian corpuscles, but that the blood reissued from these knots still arterial and then divided up into capillaries surrounding the uriniferous tubules. It now remains to trace with reference to this course for the blood, the course of the secreting tubules.

The secreting or uriniferous tubules are very long tubes intricately folded and bent and form almost all of the remaining portion of the cortex. Each uriniferous tubule begins as a sac-like dilatation surrounding a Malpighian corpuscle and forms, so to speak, the capsule around these corpuscles. The blood-vessels, however, do not really lie inside of this dilatation, but as in the case of the heart and pericardium, folded in by a reduplication of the wall. It is

at this point that almost all of the water of the secretion finds its way unto the uriniferous tubules.

This dilatation connects with the regular tubular portion of the duct. The portion immediately following the dilatation is called the *neck*. Beyond the neck the tubule becomes somewhat convoluted, and is spoken of as the *first convoluted tubule*. It then descends abruptly through the cortex down into the medulla, this portion being called the *descending limb of Henle*. In the medulla it makes a sharp turn, called the *loop of Henle* and then ascends again through medulla and cortex to almost the point of beginning, this ascending portion being called the *ascending limb of Henle*. It then usually bends and runs back almost to its Malpighian corpuscle, this portion being called, because of its convoluted nature, the *second convoluted tubule*. Near its Malpighian body it makes a sharp turn again, flowing in an opposite direction, and on account of

Fig. 130.—DIAGRAM SHOWING THE COURSE OF TWO URINIFEROUS TUBULES. (After Klein.)

A, cortex; B, medulla; C, papilla; a, a', regions free from glomeruli.
For meaning of numbers see text.

the somewhat angular turns is called the *zig-zag tubule*. This zig-zag tubule soon leads into one of the large collect-

ing tubules, into which other zig-zag tubules enter, and by means of this large collecting tubule which runs from cortex and medulla, the secretion is finally poured into the pelvis of the kidney. These large collecting ducts are called the *ducts of Bellini*. The whitish glistening threads so characteristic of the medulla are such ducts of Bellini. The course of the uriniferous tubule as just given permits, of course, of certain variations, but is with a surprising regularity the usual one.

Most of the cortex and even some of the upper portions of the medulla consists of these closely packed tubules with their accompanying blood-vessels. On cross sections each tubule shows a single layer of columnar epithelial cells resting on a small basement membrane, and it is these epithelial cells which play the physiological role of the kidney. It is these cells which pick out of the blood the nitrogenous waste products and pass them into their lumen. At the

Fig. 131.—TUBULES FROM A SECTION OF THE DOG'S KIDNEY. (After Klein and Noble Smith.)

a, capsule, enclosing glomerulus; *n*, neck; *c, c*, convoluted tubules; *f*, from the limb of Henle (in the medulla); *d*, a collecting tubule.

Malpighian corpuscle, that is, at the very head of the uriniferous tubule, water, and some salts of course, are being continually poured into the tubule, and this stream serves to wash out other substances passed into it. The fact that urea and many other nitrogenous compounds are with difficulty soluble in water at ordinary temperatures accounts for the large volume of water required by the kidney to wash out this product. We have therefore to look upon the function

of the Malpighian corpuscles of the cortex as mechanical rather than physiological, serving merely as flush basins at the top of the tubule to keep this lumen perfectly clear of obstructions, while the cells that line the tubule are the physiological agents directly concerned in picking out of the blood the waste products in question.

It may be well to repeat at this point the fact that these nitrogenous products are not formed by the kidney at all. Derived in the form of kreatin or kreatinin, or similar substances from the breaking down of the tissues, they are carried to the liver and there changed to urea and its kindred compounds, from which place by means of the regular blood stream they reach the kidney, and in this organ are merely picked up by the tubular epithelium and eliminated. It must not, however, be supposed that this elimination of the nitrogenous products is a mere physical filtration. It is an active physiological process, depending upon the vital energy of the epithelial cells that line the tubules. It is due to the special activity of these cells that these waste products are removed, and that many other almost equally dialyzable substances are not permitted to pass through. In cases of inflammation, or in cases of the more or less general disintegration of these epithelial cells, other substances do pass into the secretion and such diseases as diabetes or Bright's disease are the result.

The elimination of the water and salt in the glomeruli or the Malpighian corpuscles, is to a very large extent a physical process. This is proved by the fact that the amount of such water and salt eliminated from the kidney is to some extent directly proportional to the amount of blood which passes through the kidney and to the arterial pressure in the kidney, hence any rise in arterial pressure or any increase in the swiftness of the blood stream will usually reveal itself in an increased secretion from that organ. That it is nothing but a physical filtration is not claimed. In fact, it is probable that even the lining cells of the corpuscle exert a physiological action.

That the phenomena of secretion are controlled by nerves is evident for several reasons. States of the emotions, excessive pain, may affect the amount of such secretion through this innervation. It has, however, not been possible so far to trace these nerves to their final terminations. There is no objection, though, against believing that these nerves end in or near the epithelium cells of the tubules and capsule, and that the increased or decreased secretion is not wholly due to vascular changes. A number of drugs known as diuretics affect the kidneys, causing an increase in its secretion, but whether due to vascular changes or to a direct stimulus of the secreting cells is not clear.

THE KIDNEY SECRETION.

The amount of urine eliminated in one day is about 1,600 grams. Its specific gravity is 1,020, that is, slightly heavier than water. Its composition consists of 96 per cent. water and 4 per cent solids. These 4 per cent. solids are:

(1) Urea and its derivatives; uric acid, kreatin and xanthin.

(2) Aromatic bodies such as hippuric acid, kresol, indol, skatol.

(3) Oxalic acid in the form of calcium oxalate.

(4) Pigments.

(5) Mineral salts; sodium chloride, phosphates and sulphates of potassium, calcium, magnesium, ammonia in the form of urate. In addition to these solids slight quantities of CO_2 are dissolved in the liquid.

The most important of these solid bodies is the urea. Its chemical composition is given in the formula $\text{CO}(\text{NH}_2)_2$. It is the final product of nearly all the albumens and albuminoids which have been used up in the tissues. It is, therefore, the substance in which the nitrogen of the foods is eliminated. Reference to the chemical formula will show that it contains a relatively large amount of nitrogen. This substance is interesting as having been the first organic substance which was produced artificially in the la-

boratory. In 1828 the chemist Wöhler discovered that by allowing a solution of ammonium cyanate (NH_4CON) to stand exposed to the air it changed into urea $\text{CO}(\text{NH}_2)_2$.

It will be noticed in comparing the chemical compositions of these two substances that they have the same relative number of atoms. Urea is, therefore, but a re-arrangement of the molecular structure of ammonium cyanate. It was, of course, easy to make ammonium cyanate out of its elements in the laboratory, and so it became possible to make urea artificially in the chemist's retorts. Before this time it had been believed without question that all organic compounds, that is, compounds made by plants or animals, differed essentially from compounds made artificially. It was believed that in the construction of organic compounds vital forces were at work in addition to chemical affinities. This wonderful discovery at once showed the error of this view and opened the way for the increased study of organic compounds and for the artificial manufacture of innumerable ones now on the markets. It was the first blow to break down the distinction between organic and inorganic chemistry.

This urea may be extracted from the secretion in a pure solid form. It crystallizes in white four-cornered prisms, or when crystallized very rapidly, in fine needles. The solid crystals are soluble in water, alcohol, and many other solutions, but are perfectly insoluble in ether.

If a solution containing urea be allowed to stand for some time exposed to the air, it ferments under the action of germs falling into it from the air, and the urea uniting chemically with some of the water changes into ammonium carbonate. This change is called the fermentation of the urea. Ammonium carbonate, more familiar as the salts of harts-horn, has its peculiar characteristic odor, and it is to this substance that the odor of fermented urine is due.

The derivatives of urea, such as uric acid, kreatin, xanthin and others, are found in relatively small amounts. Under certain conditions, however, the uric acid may accumulate

in the body, and acting as a poison deposited usually in the joints, give rise to the familiar symptoms of gout and kindred diseases.

The aromatic bodies, such as hippuric acid, kresol, indol and skatol are found in very small quantities. Hippuric acid, however, occurs in relatively very large amounts in the renal secretion of herbivorous animals. The kresol, indol and skatol are substances which have resulted from the disintegration of albumens in the intestine, but having been absorbed by the blood are eliminated again through the kidneys.

The characteristic color of the renal secretion is due to a number of pigments. The best known of these is the pigment known as *uro-bilin*. This uro-bilin is probably derived from the same source as the bilirubin of the bile, that is, from the disintegration of red corpuscles, or more exactly, from the hæmoglobin of red corpuscles.

The mineral salts include a number of mineral substances which are the products of tissue disintegration, but in addition excesses of salts which have been directly eliminated from the blood. Experiments show that when certain mineral salts in increased quantities reach the blood they are at once eliminated in this manner. On this account the eating of even excessive amounts of salt has no directly injurious effect whatever upon the body.

It is sometimes of the utmost importance to the physician to be able to determine the composition of urine, especially when the presence of sugar or albumen is suspected.

Quite a large additional number of chemical substances occur in more or less minute quantities in the secretion, but the nature of these substances from a chemical standpoint is so complicated, and in the real physiology of the body they play such an unimportant role that in this discussion they are omitted altogether.

By way of summary it may be stated then that the real significance of the physiology of the kidney lies in its power to eliminate superfluous or injurious substances,

and to rid the body of the nitrogenous products resulting from the metabolism of the tissues. The kidneys are able, when necessary, to eliminate hurriedly accidentally received substances, such, for instance, as poisons of one kind or another, and so prevent the liability of injury from them. This no doubt explains the power of the body to recover from such poisonings.

While most of the work of secretion thus devolves upon the kidneys, they are able to be relieved in part by the skin, which, in addition to its functions as a protection to the body, serves quite materially in a manner similar to that of the kidney, and in cases where the kidneys have been over-worked and have lost some of their vitality, assumes this extra duty. On the other hand, when the skin for some reason is prevented from exercising this excretory function an unnaturally increased amount of work is thrown upon the kidneys.

THE SKIN.

The covering of the body, or the skin, consists of two essentially different layers; an outer layer made up of cells entirely, called the cuticle of epidermis, and an inner layer consisting almost wholly of connective tissue fibers, with contained blood-vessels, glands, nerves and so on, called the corium or cutis-vera, that is, true skin.

1.—*Epidermis*. The epidermis is a stratified epithelium composed wholly of epithelial cells. These cells are, however, not all alike, the cells of the deeper layers, next to the cutis-vera, being more cuboidal in shape than the flattened and dead cells forming the horny covering at the surface. The gradation from these dead flattened cells on the outside to the living cuboidal cells next to the corium is tolerably gradual. The lowest layer of cells, that immediately in contact with the corium, is called the Malpighian layer of the epidermis. It consists of well-marked nucleated cells of pronounced cuboidal form. It is these cells which by their division give rise to all of the remaining cells of the epidermis. The cells of this Malpighian layer

divide, and thus the top layers of the epidermis are being continually pushed further and further out by the addition

Fig. 132.—SECTION OF SKIN AND SUBCUTANEOUS TISSUE. (After Kölliker.)

a, horny layer; *b*, Malpighian layer of epidermis; *c*, corium; *d*, subcutaneous fatty tissue; *e*, papillæ; *f*, fat; *g*, sweat gland; *h*, duct; *i*, mouth of sweat gland.

of new cells from beneath. The layers of these derived cells, lying close to the Malpighian layer, also resemble the Malpighian layer in having well-defined nuclei and in their cuboidal shape. But further outward a chemical change sets in, by means of which the substance of these cells seems changed into a horny material akin to the keratin of ordinary horns, while in addition to this chemical change they become more and more flattened, losing more and more the appearance of cells until at the top of the epidermis they occur as mere horny scales, which from time to time, by contact with other bodies or by the friction of towel, etc., are broken off from the skin.

The layer of the epidermis in which this chemical change takes place is readily visible in sections as much clearer looking, due to the fact that the cells have undergone a transformation into the somewhat transparent horny ma-

terial. For this reason it has been termed the *stratum lucidum*.

It will therefore be observed that the epidermis is not at all in any way derived from the dermis beneath. The dermis is fibrous, the epidermis cellular. The epidermis is a result of the continued division of the Malpighian layer of the epidermis, and when this layer is not present, as in serious wounds, scalds or bruises, it is absolutely impossible for the epidermis to appear. Under such conditions attempts are frequently made to graft portions of the Malpighian layer from another body on to this spot, and if the graft is successful the epidermis begins to grow from these places by the proliferation of the Malpighian cells engrafted. These Malpighian cells are further of interest in the fact that in them lie the pigments which characterize the various races of mankind. A certain amount of pigment also occurs in the cells above the Malpighian layer, but it is much less pronounced, and the intense black of the colored races, or the red of the Indian is the color which shines through the somewhat transparent epidermis from the Malpighian layer at its base.

2.—*Corium*. The corium or true skin is the fibrous part of the skin lying immediately beneath the epidermis. It consists almost wholly of closely packed white fibrous tissue, containing, however, a small amount of yellow elastic fibers. In the meshes of these fibers are found connective tissue corpuscles, imbedded nodules of fat, blood-vessels and nerves, and finally the glands of the skin.

The true surface of the corium is thrown up into peculiar papillæ sometimes simple, sometimes branched, which project up into the epidermis. In these papillæ there lie in some instances loops of blood-vessels, more generally tactile corpuscles concerned in the sense of touch. These papillæ are arranged in defined rows, and as the epidermis follows these papillæ they show on the outside of the skin as those peculiar lines and furrows so evident on the

fingers and the palm of the hand. These furrows are probably not alike in any two individuals. When once formed

Fig. 133.—SECTION OF THE HUMAN EPIDERMIS, SHOWING TWO VASCULAR PAPILLÆ BE-
NEATH. (After Heitzmann.)

BP, loop of capillaries; *Dp*, duct of sweat gland; *EB* horny layer of epidermis; *PL*, stratum lucidum; *V*, Malpighian layers of epidermis.

they never change, the impressions of the furrows on an infant's thumb being identical with the impression of the same thumb in old age. In some countries impressions are made of the furrows of the fingers or thumbs of criminals in order that they may keep a perfectly trustworthy description of them, it being impossible for the criminal to change this part of his personal appearance. The absolute correspondence of an impression so taken at any time and the thumb offered in evidence would be incontrovertible proof of the identity of the man. These papillæ while present over nearly all portions of the skin are especially plentiful in those portions of the body where the sense of touch is peculiarly acute.

Through the corium run the blood-vessels, veins and capillaries. The epidermis has no direct vascular supply, although the tips of capillary loops do sometimes reach slightly beyond the Malpighian layer. The epidermis is therefore obliged to draw its nourishment from the lymph

distributed beneath it. This is, of course, in accordance with the common observation that blood is not drawn as long as the cut is confined to the cuticle.

Nerves also traverse the corium and are distributed to the contained blood-vessels and glands, while the special nerves of touch end in the touch corpuscles. Small ramifications of nerves penetrate the epidermis and run in among the epithelial cells, ending usually between these in little knob-like swellings, or terminating in certain especially modified cells which have been interpreted as sensory cells in the epidermis. A detailed description of these cells and the touch corpuscles is reserved for the chapter on the "Special Senses."

Fig. 134.—SECTION OF THE SKIN SHOWING TWO PAPILLÆ. (After Biesiadecki.)

a, vascular papilla, containing a capillary loop from the artery *c*; *b*, sense papilla, containing a tactile corpuscle *t*; *d*, *f*, *f*, three nerve fibers, running to and around the papilla.

The corium is held to the underlying tissues by a loose coat made up almost wholly of connective tissue fibers.

In some places this binding coat is rather poorly developed, leaving the skin loose and giving it much latitude of movement.* In others the skin is bound firmly down to

the flesh and the transition from the skin is so gradual as to be indeed difficult to follow. The fibrous nature of the corium may be a matter of easy observation on any piece of leather, a torn edge here displaying frequently very satisfactorily the tanned shreds of fibers which go to make up the material. The process of tanning consists in nothing more than taking plexuses of connective fibers, forming the corium or true skin, and treating these with a substance called tannin, by means of which they are hardened and transformed into a substance which increases their strength as well as their resistance to decay. It need not be added that the epidermis does not figure at all in this process.

SPECIAL MODIFICATIONS OF THE EPIDERMIS.

1.—*Nails.* The epidermis is in certain portions of the body specially modified to form hairs or nails. A nail is a portion of very much-thickened epidermis, the component cells of which are much more closely packed, and the chemical change of which into keratin or horn is more complete. The posterior part of a nail is concealed in a groove of the skin, and it is at this point that the nail increases in length by the formation of new epithelial cells. The nail grows in thickness by the proliferation of cells from the bed of the nail, the thickest portion of the nail being the exposed end. The nail usually presents near its root a lens-shaped white area known as the lunula. This whitish appearance is due to an opacity at this point, resulting from the thickness of the nail bed immediately under it, the cells of which are in very active division to increase the thickness of the nail. The cells of the root and bed of the nail, in active process of division are soft, while those longest formed and next the surface or end of the nail are in increasing degrees horny, differing, however, from the horny cells of the ordinary epidermis in the fact that they seem to possess spiny processes, by means of which they are firmly interlocked and united.

That the nail is an epidermal structure is not only proved from its composition of epidermal cells, but also proved by the source from which the root of the nail is derived. In very early life, as early as the third month of uterine life, the epidermis at the point where the root of the nail is to form bends inward forming a groove, which groove finally imbedded in the deeper layers of the skin becomes the matrix for the growing nail. It is said that the continued rate of growth of a nail is about one-thirtieth of an inch per week. As in case of epidermis in any part of the skin a new nail is able to appear only when in the pulling away of the old one the deeper layers, the Malpighian layers, of the nail root are left intact.

2.—*The Hair.* A second modification of the epidermis is the hairs. They appear about the third or fourth month of embryonic life as growths from the Malpighian layer down into the deeper parts of the corium. This ingrowth soon divides into an outer wall of epidermal tissue which becomes the wall of the hair follicle, and an inner portion which appears as the hair. The growing portion of the hair is at the bottom of the hair follicle where the Malpighian cells are in constant process of division. This point of growth is spoken of as the root of the hair, and on account of the continued proliferation of new cells is highly vascular. These blood-vessels really lie in the corium, but the corium at this point usually extends some distance into the hair root, like a papilla, on which and around which the dividing cells of the hair root are placed. At the root the cells which go to make up the shaft of the hair are more or less alike, but a differentiation at once begins, and along the shaft proper the following structure of the hair may be easily made out with the microscope.

Surrounding the hair is a single layer of flattened cells forming a kind of scaly covering. This is called the *hair cuticle*. Beneath this thin cuticle is the real *fibrous* portion of the hair. In most hairs this fibrous portion consti-

tutes the entire remainder of the shaft. It consists of delicate fibers closely packed together, running of course in the longitudinal direction of the shaft. Finer investigation reveals that these fibers are in turn composed of flattened and elongated cells. On these dried and elongated cells remnants of nuclei may sometimes be still visible. In the cells that make this fibrous portion there is a deposit of pigment to which the hair in question owes its color. In older hairs air spaces may arise by a kind of drying process, which by their reflection of the light give to the hair a grayish appearance. Such hairs, when soaked in certain liquids become entirely transparent, these air spaces being filled up with the liquid in question, but when the hair is again dried the liquid evaporates, the air again enters these spaces and the old color reappears. It is said by some observers that the pigment of the hair, be it black, brownish or reddish, is carried to the cells at the root of the hair by peculiar wandering pigment cells reaching it.

Fig. 135.—HAIR-FOLLICLE, IN LONGITUDINAL SECTION. (After Biesiadecki.)

In some cases the interior of the hair is occupied with a kind of medulla or *pith*. This pith is composed of rows of cells of a generally angular form. It is especially apt to appear in advancing years, and the whiteness of hair is usually due to the contained air which lies in the spaces among these cells, and in some instances actually in the cells. These air spaces are of course produced by the drying of the hair in its exposure to the atmosphere.

On cross sections the shaft of the hair is usually round. In some individuals, however, and in certain races it is more regularly flattened. Such hairs show a natural tendency to curl on account of the unequal growths at the different angles. The size of these hair shafts is also a racial characteristic. It is rather small in the Caucasian race, much larger in the Mongolian, and reaches possibly its maximum diameter in the American Indian and the Japanese.

It need not be pointed out that like the nails and epidermis, hairs are able to be replaced only when the reproducing Malpighian layer at the root of the hair is left intact.

Sebaceous Glands. Along the tube of the hair follicle in which the shaft is immersed in the skin there opens regularly a sebaceous duct carrying a fatty secretion from the sebaceous gland into the follicle, there to be poured upon the shaft of the hair. This sebaceous gland is a flask-like outgrowth from the epidermal cells of the follicle, and is therefore epidermal in its origin. The function of this secretion is not only to preserve somewhat the vitality of the hair, but by being poured upon the skin to keep that in pliable condition and to protect the same from excessive evaporation. The secretion from these sebaceous glands is of a fatty nature. In places where the hairs are minute these sebaceous glands seem to open directly on the surface of the skin, an arrangement especially noticeable on the skin of the face. The secretion of such glands may frequently become thickened and so choke up the glands in question, a condition which usually results in the formation of a pimple, which is nothing more than an attempt of nature to empty the gland by a process of suppuration. Sometimes the mouth of the gland becomes filled with particles of dust or dirt pressed down into them, and so gives rise to the familiar blackhead. These glands seem to be emptied as a rule by the contraction of muscles which are found attached to each hair follicle. These muscles are bands of plain muscular tissue attached at one end to the under surface of the corium, at the other to the lower portions of the

hair follicle. By their contraction it is probable that a little of this sebaceous secretion is squeezed out of the gland into the follicle. These muscles are specially apt to contract under certain conditions such as exposure to the cold, and by this contraction the follicle is pulled upward and projects slightly beyond the rest of the epidermis, producing the little elevations described under the somewhat senseless term of goose-skin.

These glands as well as hairs are absent from certain portions of the skin such as the palms of the hands and the soles of the feet. A very specialized form of such a sebaceous gland is found among the tail feathers of certain birds and is called the *uro-pygeal* gland. The secretion here is so abundant that the bird in question may by means of its bill take the secretion for the oiling of its entire coat of feathers. A special form of these glands in the human body is found along the upper and lower eyelids. These glands are known as the *Meibomian glands*. The function of the secretion at this point is to keep the edge of the lids somewhat oily and so prevent the tears from running out of the eye over these eyelids. This is accomplished by taking advantage of the familiar fact that water does not very readily run across an oiled surface. In the ear there are found certain sebaceous glands secreting a thick, fatty substance familiar as the ear-wax. These glands, however, are anatomically not true sebaceous glands at all, in spite of the nature of their secretion, but belong to the tubular sweat glands. It is in fact just possible that these are not modified sebaceous glands at all, but are really sweat glands which have taken on a different function.

THE SWEAT GLANDS.

Distributed all over the body, except on the palms of the hands and on the soles of the feet, are long tubular glands known as the sweat or sudoriferous glands. These are simple tubular glands, the lower portion of the tube, however, being rolled up into a coil. This coil lies in the

deeper portions of the corium, or more generally in the subcutaneous tissue. From this coil a tubular duct runs through the corium and epidermis, carrying its secretions to the surface of the skin. Instead of running directly upwards the duct winds through the corium and epidermis in a spiral cork-screw fashion. A cross-section of the tube of this gland shows it to be composed of an investment of connective tissue and an inner layer of columnar cells enclosing the lumen. The coiled portion of the tube in the subcutaneous tissue is richly supplied with blood-vessels and nerves. The reason for this coiling of the tube is no doubt explained in the saving of space. The explanation of the spiral winding of the duct through the skin is not apparent. These glands are especially plentiful on the forehead and under the arms. Rough calculations have placed the number of sweat glands on the entire body at about 2,000,000.

1.—*Nerves.* That these glands are under the control of the nervous system is beyond question. It is an every-day observation that states of emotion, fright or pain directly affect the perspiration of the body and thus clearly point to the existence of sweat centers in the spinal cord and brain. But evidence still more direct is at hand. It is possible to amputate a limb of a cat, for instance, and by stimulating the sciatic nerve, along which the sweat fibers run, to produce droplets of sweat on the balls of the feet, and this even when there is no increase in the blood supply; in fact, when the circulation has entirely stopped. This is conclusive proof that the process of sweating is not a simple filtration of water and salt from the lymph or blood in and through these glands, but that it is a physiological phenomenon under direct nervous control, and to a large extent independent of vascular conditions.

Experiments seem to point to the existence of lower sweat centers in the spinal cord which may, however, under special conditions be controlled by higher centers in the

brain itself. The existence of such higher sweat centers of the brain was just pointed out in the familiar experience of everybody that strong emotions, especially great anxiety, at once shows itself in an increased activity of these glands. There are certain drugs which have a very specific effect on these glands. Thus, pilocarpine will stimulate the glands to active secretion, while, on the other hand, the administration of atropine more or less completely checks it.

2.—*Composition of the Sweat.* The secretion of these glands, or the sweat as it is called, has a composition not yet well determined. It is difficult to get the fluid free from a sebaceous admixture. It seems to consist, however, of water, common salt and traces of a number of alkaline salts. The most important organic constituent of sweat is the urea. This becomes especially plentiful when for some reason the function of the kidneys has been impaired. But even when these are normally discharging their duty there is a larger proportion of urea in the sweat than could be accounted for by simple filtration, pointing to the fact that the cells which make up the tube of the sweat glands in an active physiological way pick up the urea from the blood and eliminate it from the body in the perspiration. In addition to this urea fine chemical analyses have shown the presence in minute quantities of some of the other substances found in the secretion of the kidneys. For such reason the skin has been called an excretory tissue in addition to a protective one and classed physiologically with the kidneys and lungs. It was formerly believed that the death which soon followed the varnishing of the skin of an animal, a procedure which stopped up all the pores of the skin, was due to the fact that this excretory function of the skin had been stopped. Such an explanation is, however, wrong, later experiments proving that the death of such a varnished animal results from the increased loss of heat which the varnished surface of the body radiates away.

It was in the chapter on heat pointed out in what an important and integral way the perspiration figured in maintaining a constant and unvarying temperature of the body.

3.—*Origin of Sweat Glands.* In their origin sweat glands, too, are epidermal. They arise in early embryonic life as outgrowths of the epidermis, these down-growths soon becoming hollow and with secondary changes transforming themselves into the adult structure of the gland.

CHAPTER XIX.

THE GENERAL ANATOMY AND PHYSIOLOGY OF THE NERVOUS SYSTEM.

In the discussion of the various systems of the body so far, they have been treated as acting more or less independently of each other. We have now left to consider that large system whose function it is to co-ordinate these various systems into a harmoniously working whole. This statement of the function of the nervous system covers at one sweep its entire physiology, notwithstanding the multitude of ways in which this is accomplished. Possibly the most fundamental point in discussing this system is its oneness or unity. Sometimes for arbitrary reasons or for mere convenience sake we speak of several nervous systems. This is physiologically wrong. The entire system of nerves, ganglia and higher centers are all bound together and physiologically are a unit. This is true even in spite of the fact that certain parts of this system have more or less specialized functions, for even in this case the co-ordination and the successive subordination is finally so perfect that unifying results only are reached. It seems desirable, however, in order to facilitate the discussion of these nervous tissues to adopt the usual classification into—

First, the cerebro-spinal system, including the brain and the cranial nerves, and the spinal cord and the spinal nerves.

Second, the sympathetic system, including two chains of ganglia lying along the back-bone and extending from the upper cervical through the lumbar region, and the nerves which emanate from these ganglia.

Third, the sporadic system, not a connected system at all, but consisting of various ganglia scattered throughout

the body not included in the two other systems. Such ganglia are those of the heart, the plexuses of Auerbach and Meissner in the intestine, the intrinsic ganglia of blood-vessels, the solar plexus of the mesentery, etc. A sharp distinction between these three systems cannot at all be drawn. The spinal nerves are connected with the sympathetic nerves, and both these nerves may run into sporadic ganglia.

NERVOUS ELEMENTS.

In studying in detail any of these systems two kinds of nervous structures are at once discernible:

1.—*Nerves, Nerve Trunks and Plexuses.* By dissecting a body one meets almost everywhere whitish looking threads which are nerves. These might easily be mistaken for tendon threads or other connective tissue fibers. If by means of the scalpel the course of such a thread or cord is followed it is soon seen to divide and sub-divide until the finer ramifications are lost among the muscles or glands or in the skin. If the microscope should be called to aid it would be possible to actually see these nerve terminations in many instances, such as their endings in the nerve-plates of the voluntary muscles or in the tactile corpuscles of the skin. If, on the other hand, one should follow the course of such a nerve inward, it would be seen to unite with other nerves, until finally the nerve would be found entering the spinal cord or brain, or at least some central ganglion. Such whitish cords are called nerve trunks. A cross-section of such a nerve trunk would show that it is composed of very many smaller cords, the nerve fibers, and that the trunk is really nothing more than a collection of fibers running in the same direction wrapped in a common envelope of white connective tissue. It is this white connective tissue envelope and not the nerve substance itself which gives to the nerve trunk the color in question. Not infrequently by following a nerve trunk it might be seen to send off communicating branches to other nerve trunks, and

these in turn to still others, and so there would be produced networks of fibers. These networks are called plexuses. It is by means of these plexuses that an individual nerve fibril of one trunk may find its way into other trunks and so reach removed parts of the body. This makes it possible for a nerve trunk to contain near its end fibers which it did not have at its beginning, but which reached it along its course. While such plexuses are very generally distributed all over the body there are peculiarly large ones in the shoulder and lumbar regions, forming respectively the spinal nerve plexuses that go to the arms and limbs.

2.—*Nerve Centers or Ganglia.* When the course of a nerve is followed inward it is soon found to end either in the brain, spinal cord, sympathetic system, or in isolated ganglia over the body. All these structures named are nerve centers; that is, they are nervous centers from which nerve fibers arise. These nerve centers may be large, as many of those in the brain, or they may be small aggregations of nervous tissue like the individual centers of the sympathetic system. Centers lying more or less separate and having a distinct outline are called *ganglia*.

A ganglion is in essence nothing more than a group of nerve cells with which the nerve fibers entering the ganglion are physiologically connected. These groups of nerve cells are of course usually surrounded with a more or less complete coat of connective tissue intended for protection. While anatomically this description suits all ganglia, physiologically there are distinct kinds.

From this it will be seen that the entire nervous system is composed of nerve cells more or less grouped into distinct ganglia and of nerve fibers which run out from these ganglia connecting them with each other, or connecting the ganglia with distant glands, muscles, skin, etc. A detailed histological description of these nerve fibers and their coats, and of the nerve ganglia and their aggregation in turn into larger centers is reserved for the chapter on the

finer architecture of the nervous system, it being the intention in these preliminary paragraphs to deal simply with those points of the nervous system included under its gross anatomy.

THE BRAIN AND SPINAL CORD.

By far the most important system, both with reference to its special psychical functions and its general control over the other systems, is the cerebro-spinal system. This consists of the brain and spinal cord, and the nerves issuing from them. The brain and spinal cord are continuous through the foramen magnum, a large opening in the occipital bone.

The Membranes of the Cerebro-Spinal System.

In the examination of these systems one is peculiarly impressed with the efficient way in which they are enclosed within bony and membranous coverings. The brain is encased in the bony cranium, while the spinal cord is almost equally protected in the neural arches formed by the vertebræ. In addition to this bony envelope both brain and spinal cord are covered with three membranes. Lying next to the nervous tissue is a delicate thin membrane called the *pia-mater*. This dips down into all the convolutions and configurations of brain and spinal cord, and serves especially to carry the blood-vessels nourishing them. Lying next to the bone is an exceedingly tough dense membrane formed almost wholly of white closely woven connective fibers called the *dura-mater*. Between the *dura-mater* and the *pia-mater* there is a spongy membrane called, on account of its web-like nature, the *arachnoid* membrane. The *dura-mater* figures not only as an enveloping membrane of the brain and spinal cord, but serves as a periosteum for the cranial bones as well. While these membranes surround the brain very closely the *dura-mater* does not invest the spinal cord in the same way, but here frequently leaves quite a space between the *pia-mater* and itself, in this way covering even the spinal root ganglia lying along the spinal

cord. In fact, the dura-mater is loosely attached around the spinal cord and does not serve as a periosteum for the

Fig. 136.—SECTION OF THE SPINAL CORD SHOWING THE ARRANGEMENT OF ITS INVESTING MEMBRANES. (After Key and Retzius.)

a, dura mater; *b*, arachnoid; *c*, posterior septum; *d, e, f*, subarachnoid tissue; *h*, anterior root fibers cut; *k, l*, subarachnoid space.

vertebræ, these bones having a periosteum of their own. In the meshes of the arachnoid membrane there is usually contained a small quantity of lymph-like liquid called the cerebro-spinal liquid. It is not probable that this has any specific function.

The Spinal Cord.

The spinal cord is a cylinder of nervous matter enclosed in the neural arches. Its average length is about seventeen inches. It does not, therefore, reach from the cervical region entirely through the lumbar. In fact, the neural space in the lower lumbar region is occupied by a number of nerve fibers from the spinal cord, while the cord itself is here reduced to a slender filament called the *filum terminale* which runs to the end of the neural canal in the sacrum.

The cord is not quite round in cross-section, it being a little wider from side to side than from before backwards. Its average diameter is about three-fourths of an inch. It

shows, however, two enlargements along its course, one in the cervical region called the cervical enlargement, and a second at the beginning of the lumbar region called the lumbar enlargement. It weighs from one and one-half to two ounces.

The spinal cord gradually shades off into the brain, and the point at which one is said to cease and the other to be-

Fig. 137.—CROSS-SECTION OF HUMAN SPINAL CORD, TWICE NATURAL SIZE.

A, cervical region; B, dorsal region; C, lumbar region; a, anterior root; p, posterior root.

gin is quite arbitrary. There is no sudden transition from one to the other. If a cross-section be made, the cord is seen to consist of two halves, this bilateral arrangement being caused by two deep grooves or fissures running longitudinally along the cord and almost separating it into a right and left lobe. The division, however, is not complete, the anterior and the posterior fissures not meeting, but the two hemispheres being connected near the middle by a commissure consisting partly of gray matter, and anterior to this of white matter. The posterior fissure reaches down to the gray matter, and the anterior fissure to the white commissure just referred to. In the center of the gray commissure is the cross-

section of a canal running lengthwise through the spinal cord and connected in the brain with the ventricles. This is called the central canal, or *canalis centralis*. It probably has no specific physiological function, but its presence is easily explained by reference to the embryonic development of the spinal cord and brain.

A cross-section of the cord does not show a uniform appearance, but shows a grouping into two tissues, so disposed that the central gray substance is arranged somewhat

in the form of a capital "H." The commissure of this H is the gray commissure just mentioned, which contains the central canal. Each limb of the H shows, however, a shorter and thicker anterior branch and a somewhat more slender posterior branch. These are called respectively the anterior and posterior horns or cornua. The remaining portion of the cord outside of this central H is composed of white matter which examination with the microscope reveals to be cross-sections of nerve fibers which are here passing along the cord. The central gray-shaped H owes its grayish color to the fact that it contains aggregations of nerve cells, which are always gray, and of nerve fibers which do not possess the white medullary coat, and so are also gray. On the other hand, the white appearance of the surrounding portions is due to the presence of the white medullary coats of the nerve fibers. Just anterior to the gray commissure is the white commissure already mentioned, formed by fibers connecting the white matter of one side with the white of the other. By means of the horns of the gray matter the area of the cord is divided into several easily distinguishable regions. The white matter included between the anterior horns is spoken of as the *anterior white column*, that included between the posterior horns is called the *posterior white column*, while that portion on each side lying in the hollow of each of the crescent-shaped limbs is called the *lateral column*. These columns are of the deepest interest in the discussion of the course of fibers through the brain and cord, a point to be treated further on

The Spinal Nerves.

If a cross-section of the cord had been made between the origins of the spinal nerves, the section as just described would have included all the points visible. If, however, the section should have passed through that region of the cord from which a pair of spinal roots takes its issue several additional points would appear. Running out from the anterior and posterior horns, fibers might be traced leaving

the cord, running for some distance laterally from the cord as separate trunks, but before leaving the dura-mater, uniting on each side to form a single spinal nerve. On the posterior root of the spinal nerve just previous to its union with the anterior root, occurs a ganglion called for evident reasons the *posterior spinal root ganglion*. The physiological significance of these roots need not concern us here, save the preliminary statement that the fibers which leave the cord from the anterior horn are *motor* in their nature; that is, carry impulses outward towards the muscles, while the fibers entering at the posterior horn are *sensory* fibers carrying sensations inward to the cord and brain.

Immediately after the formation of the spinal nerve by the union of sensory and motor trunks it divides into three branches, a posterior primary, distributed mainly to the skin and muscles of the back, an anterior primary, giving off nerves for the sides and ventral portion of the trunk and for the limbs, and a third communicating branch which runs to the neighboring sympathetic ganglion. It is through this connecting branch that the co-ordination and subordination of the sympathetic system is effected.

Thirty-one pairs of such spinal nerve trunks arise from the spinal cord, leaving the neural canal through the intervertebral foramina. Each of these spinal nerves has a specific name, the name being derived from the vertebra situated immediately in front of it. Thus, the nerve that arises between the second and third thoracic vertebræ is the second thoracic spinal nerve; that which arises between the fourth and fifth lumbar vertebræ is the fourth lumbar nerve. The spinal nerves which arise in the lower lumbar, sacral and coccygeal region run down through the neural canal, occupying the space in this portion which the cord has further up, the cord being here reduced to the *filum terminale*. This big bunch of nerves is called the horse's tail, or *cauda equina*.

GENERAL DISTRIBUTION OF THE SPINAL NERVES.

It would be quite undesirable from the standpoint of an elementary text-book to give with surgical exactness the distribution of these thirty-one pairs of spinal nerves. Suffice the general statement that these spinal nerves supply the voluntary muscles of the neck and the trunk; that as the phrenic nerve they control the diaphragm; as sensory nerves they are distributed to the entire skin of neck, trunk and limbs, while as motor nerves they innervate the muscles of the limbs and figure in all their voluntary movements. In a word, it may be said that the spinal nerves innervate all that portion of the body below the head from which we derive special sensations or in which we are able to produce voluntary movements. In addition to this, communicating branches reach the sympathetic system and bring it into physiological connection with the brain and spinal cord.

THE BRAIN.

Under the term "brain" is included all that portion of the cerebro-spinal system lying above and including the medulla oblongata. It consists of three main divisions apparent at once to the unaided eye: the large fore-brain or *cerebrum*, the hind-brain consisting of the *cerebellum* and the *medulla oblongata* lying immediately below it, and the mid-brain lying between the cerebrum and hind-brain and consisting of the *corpora quadrigemina* and *crura cerebri*.

Weight. The weight of the brain varies considerably, an average weight being in the neighborhood of fifty ounces in the adult male and about forty-five in the female. Of this weight of fifty ounces the fore-brain or cerebrum weighs about forty-four, being therefore very much larger than the hind-brain and mid-brain together. In fact, it laps entirely over the other portions, so that a view from above would not disclose either the cerebellum or mid-brain. This especial development of the fore-brain is, however, a characteristic of the human species alone. As we

go down the animal scale the relative difference decreases until in some of the lower vertebrates the fore-brain is the smallest of the divisions. This is especially true in the fishes, in which the mid-brain or optic lobes form the bulk of this organ. The cerebellum and medulla, on the other hand, do not decrease in the same proportion, but are relatively large in all animals. The disproportionate size of the human cerebrum makes possible those higher psychical functions which belong to man alone.

Convolution. The cerebrum is divided by a deep median fissure into two almost separate halves called the *cerebral hemispheres*. Viewed from the top and sides the surface of the cerebrum is thrown into deep convolutions or gyri. While these convolutions occur in the brains of many of the lower animals they are much deeper in the human species, and there is even an increase in the depth as we proceed from the lower to the higher races of mankind. These convolutions find their explanation in the fact that the surface of the brain is thereby materially increased. Rough calculations on the actual surface of the average brain show that it may reach an extent almost equal to that of the larger portion of the trunk itself, but by means of these foldings this surface is enclosed in the relatively small cranium. The desirability for a large cortical surface is apparent when it is remembered that the principal cells concerned in sensation and volition are found here. While these convolutions seem to run without any appearance at regularity, and while in detail they do differ somewhat in different individuals, their general plan is constant, and by means of them spots on the cortex of the brain are localized. A few of the principal convolutions only, need be mentioned here. One of these is the large *fissure of Sylvius*, on each side of the brain which lies between the lateral lobes of the brain and the main portion, running from the base of the brain upwards and backwards towards the occipital region. Connecting with the fissure and running

upwards towards the top of the brain separating from the main portion of the cerebrum, the frontal lobes, is the *fissure of Rolando*. The fissure of Sylvius is important as being the most apparent and deepest furrow. The fissure of Rolando is interesting as being the region along which many of the centers of conscious volition have been by experiments localized. If the fissure of Sylvius be opened with the fingers it discloses to view a lobe of the brain hidden in this fissure known as the *Island of Reil*. If from the top the two cerebral hemispheres be pushed apart it will be seen that the median fissure reaches down to a white band of connecting fibers which runs from one hemisphere to the other. This band of connecting fibers is called the *corpus callosum*.

Base of Brain. If now the base of the cerebrum be studied it reveals a number of structures easily recognizable with the unaided eye. Lying immediately under the frontal lobes are the *olfactory lobes*. These are bits of grayish, nervous tissue and are the nerves concerned in the sense of smell. They are quite inconspicuous in man, but in some of the lower animals reach very large proportions, sometimes being larger than the cerebral hemispheres themselves. This may probably be interpreted as meaning that the sense of smell is relatively dull in man as compared with many of the lower forms, which have to rely upon this sense in searching for their food or avoiding their enemies.

Immediately back of the olfactory lobes the large *optic* nerves arise. These optic nerves seem to cross at the base of the brain in the *optic commissure* and are continued back into the brain beyond this commissure as the *optic tracts*. These tracts may be followed some distance around the *crura cerebri* into the tissue of the brain. There is not a complete crossing, however, of the optic nerves at the commissure, but the decussation is limited to half of the fibers so that the optic nerve on each side consists of half of the fibers from its own optic tract, the other half from the opposite optic tract which reached it in the commissure.

Immediately behind the optic commissure there is a funnel-like projection called the *infundibulum*. At the end of this infundibulum lies a peculiar gland-shaped body familiar as the *pituitary body*, a structure described in the chapter on the ductless glands. The infundibulum is hollow, the cavity in the same being an extension of the third ventricle. On account of the thinness of its walls and the difficulty with which the pituitary body is removed from the skull, these structures are usually torn off in prepared brains and the place of the infundibulum is indicated only by an opening leading into the third ventricle.

Posterior to the infundibulum and just in the angle of the crura cerebri lie two small whitish elevations each about the size of a small bullet, the *corpora albicantia*. It will be pointed out further on that these corpora albicantia are projections caused by the sudden bending back at this point of the fornices, which are bands of nerve fibers running through the brain. These fibers run to the bottom of the brain as if to leave it at this point, and then make a sharp turn and run almost directly backwards. It is this lobe of the fornix which projects from the brain below, and which, consisting of white nerve fibers, gives to these structures their peculiar appearance.

Following this it may be noticed that the continuation of the cord here divides into two forks, one running to the right hemisphere and the other to the left. These two forks are called the legs of the brain, or the *crura cerebri*. They are, of course, the big tracts by means of which the hemispheres of the brain are put in direct communication with the nervous system below.

Near the middle of the crura cerebri arises the third pair of cranial nerves, the stumps of which usually appear as relatively large nerves.

A little distance farther back lies the *pons Varolii*, readily distinguishable as a thickened band around the medulla. This pons or bridge consists largely of fibers which run across the cord at this point and connect the two sides

of the cerebellum. In a general way, disregarding certain sets of fibers the cerebellum and the pons may be compared to a signet ring, the band of which is the pons, the signet being the large cerebellum itself, the finger the cord passing between. It is well to repeat again that this analogy is not quite true either anatomically or physiologically, but the detailed course of the fibers at this point will be followed in a succeeding chapter.

Immediately back of the pons is the *medulla*, with its widest portion near the pons and gradually tapering backward until it reaches the size of the cord into which it gradually blends. Along the pons and the medulla arise the remaining cranial nerves.

While all of these structures at the base of the brain have been described in connection with the cerebrum, some belong to the mid or hind-brain in reality. The fore-brain extends to the beginning of the *crura cerebri* and the mid-brain as seen from below includes the *crura cerebri*, while the hind-brain consists of the pons, medulla oblongata and cerebellum. If by means of the fingers the cerebrum and cerebellum be pushed apart by tearing away the brain coverings which hold them in place, here, the dorsal view of the mid-brain appears. This is marked by four hemispherical eminences called the *corpora quadrigemina*. Of these the anterior pair is much larger and is called the *nates*, the posterior pair the *testes*. These corpora quadrigemina occupy on the dorsal side of the mid-brain the position held by the *crura cerebri* on the base. If the cerebrum and the mid-brain be torn apart somewhat, there will be seen lying, just anterior to the corpora quadrigemina and on the median line of the body, a small gland-like structure about the size of a pea or smaller, known as the *pineal gland*. This pineal gland is not connected with the mid-brain at all, but arises from the two optic thalami lying immediately anterior. This structure was the object of some speculation formerly when the view was advanced that being the only unpaired structure in the brain it must be the seat

of the soul, the soul being considered an individual and not divisible into halves. Such speculation soon came to grief, however, when it was discovered that this pineal gland was relatively larger in the lower animals, and as greater dimensions of soul were not to be attributed by these thinkers to the brute creation, this view had to be abandoned. Its scientific explanation is now, however, evident, it being nothing more than the stump of an optic nerve which in the early history of evolution connected with a third eye. All traces of the eye are gone in all the higher animals, but the proximal stump of the nerve is still present. In some of the lower animals, certain forms of lizards, the pineal gland still connects with a retinal structure, although even here it has ceased to be functional.

The surface of the cerebellum differs essentially from that of the cerebrum. It has no true convolutions, although marked by a series of transverse ridges. It is divided into three lobes, a central or middle lobe and the two lateral lobes. At the outer lower edge of each lateral lobe there is a small added lobe called the flocculus.

The Interior of the Brain.

The Ventricles of the Brain. Before describing the structures lying within the brain it seems desirable to show the topography of the ventricles of the brain in order that the other structures may be located with reference to these.

The central canal of the spinal cord runs upward into the medulla and here widens out into a large ventricle called the *fourth ventricle* of the brain. This ventricle lies immediately below the cerebellum. Instead of lying in the center of the medulla it lies very close to the dorsal surface, that is, next to the cerebellum, and separated from it by a very thin wall only. This wall is easily torn and the interior of the ventricle laid bare. The width of the ventricle here is considerable, a half inch or more. Proceeding upwards the ventricle again narrows into a small canal in the mid-brain and as such a small canal passes entirely through

this part. This small canal is known as the *aqueduct of Sylvius*, or more usually the *iter*. This iter lies between the *copora quadrigemina* and the *crura cerebri*. Immediately upon reaching the cerebrum the iter enlarges into the *third ventricle*. This ventricle lies between the optic thalami and extends down into the infundibulum already described. Both the fourth ventricle, the iter, and the third ventricle lie in a median position. At the forward end, the third ventricle narrows into two openings, known as the *foramina of Monro*, and each of these opens at once into a large *lateral ventricle* which lies within each cerebral hemisphere. These lateral ventricles are relatively very large, and extend from near the front of the brain to the occipital region, while a horn of this ventricle dips down almost to the bottom of the lateral lobes.

The two lateral ventricles are separated from each other by a thin partition, which partition in front of the third ventricle is called the *septum lucidum*. This septum lucidum is really double, enclosing a small space within itself. This space is called the *fifth ventricle* of the brain. It is necessary, however, to bear in mind that this fifth ventricle is not a true ventricle at all. It has no connection whatever with the other ventricles, and is really only an accidental opening formed in the septum lucidum as the brain developed.

Interior Structures. If with a scalpel sections of the cerebrum parallel to the base of the brain should be cut off there would soon be reached the bottom of the fissure dividing the brain into two hemispheres. Examination of this bottom shows it to be made up of a sheet of white nerve fibers extending from one hemisphere to the other. This sheet of connecting fibers is the *corpus callosum*. If after having been laid open, the corpus callosum is gently cut loose and lifted off the structures below it, the two lateral ventricles come to view, the corpus callosum forming the roof of these lateral ventricles. The two lateral ventricles

can then be easily seen to be separated from each other by a band of tissue running perpendicularly along the median line of the brain from the corpus callosum to the floor of the ventricles, while towards the front of the brain this septum would be continuous with the septum lucidum.

If the corpus callosum should be entirely removed the entire floor of each ventricle is exposed. In the anterior portion of this floor lie the *corpora striata*, eminences of gray nerve matter each about the size of an almond. In position these corpora striata lie just to the right and left of the septum lucidum. The floor in the posterior portion of the ventricles is made by a triangular mass of white tissue with its broad side towards the mid-brain and tapering towards the septum lucidum. This white tissue bends abruptly downward posteriorly at each side and runs to the base of the lateral lobes of the brain following the ventricle in this region. This broadened portion is called the *hippocampus*. Towards the septum lucidum this becomes gradually narrower and where it bends downwards it is on each side called the *fornix* (pillar). Immediately under the fornix on each side, and between it and the optic thalamus beneath is the foramen of Monro already referred to. The fornices are not continuous with the septum lucidum, as they seem at first sight to be, but bend abruptly downwards in front of the third ventricle reaching the base of the brain. Here they make a sharp turn recognizable as the corpora albicantia, and end in the optic thalami.

The hippocampi are like the corpus callosum composed of nerve fibers and are one of the most important bands of association fibers in the brain. If by means of the scalpel the fornices be cut and this entire bit of nerve fiber matter lifted off or folded back there are disclosed two large bodies immediately below them called the *optic thalami*. The optic thalami lie immediately anterior to the nates. Between the optic thalami lies the third ventricle, the roof which is therefore practically formed by this band of nerve fibers just removed.

The continuation of the third ventricle down into the infundibulum is now apparent. Running across the third ventricle from one side to the other may be seen several commissures serving to connect the sides. The attachment of the pineal gland to the optic thalami is now also evident. From the blood-vessels which supply the brain several arterial branches reach the third ventricle and are from the third ventricle carried through the foramina of Monro into the lateral ventricles, where as the *choroid plexus* of the brain they line the walls of these ventricles more or less completely and serve to nourish them. It not infrequently happens that these delicate blood-vessels are injured and a hemorrhage of the brain occurs, inducing apoplexy.

If an incision should be made through the corpus striatum it would be seen to be divided in its posterior region into an inner and outer portion by a band of white nerve fibers. This band is called the *internal capsule* and consists of a large number of nerve fibers which are on their way from the surface of the cerebral hemisphere to the cord.

The Cranial Nerves.

Twelve pairs of nerves arise from the base of the brain, the names of which in their successive order and the distribution of which are as follows:

First. The *olfactory* nerve passing through the cribriform plate of the ethmoid and innervating the membrane of the nose. It is the nerve of smell. It differs materially from other nerves in that the fibers are not wrapped up into definite nerve trunks by a connective tissue epineurium.

Second. The *optic* nerves leading to the eye and spreading out there in the retina. They are wholly sensory, carrying the visual sensations to the brain.

Third. The *motores oculi*. These arise from the crura cerebri and are distributed to the muscles of the eye, excluding, however, the external rectus and superior oblique. They are motor nerves and control the movements of the eye which these muscles produce. In addition to that, fibers

from the *motores oculi* reach the muscles of accommodation and the muscles of the iris. It is this latter nerve which in a reflex way causes the contraction of the pupil when the eye is subjected to an increased amount of light. It is interesting to note that a contraction or relaxation of the muscles of the iris is never confined to one eye alone, but that both eyes move in unison. It is evident, therefore, that the *motores oculi* of the right and left eye are in direct anatomical communication with each other at or near their place of origin. Fibers from this same nerve control the muscles of the upper eye-lid. That this nerve is the most important motor nerve of the eye may be readily seen from its innervation, and a section of the nerve induces at once the relaxation and closing of the upper eye-lid; the impossibility to move the ball of the eye, a dilatation of the pupil, and the impossibility of a contraction of the same even when subjected to a strong light, and finally a paralysis of the accommodation of the eye so that the focus of the eye is immovably set for distant objects.

Fourth. The pathetici. The *pathetici* leave the brain immediately anterior to the pons Varolii, innervate the superior oblique muscles and so help to control the movements of the eye in so far as they are affected by these muscles. The cutting of the *patheticus* nerve seems to show no immediate results in the eye, but an animal so treated is unable to fix its gaze upon a certain point when its head is turned. By the paralysis of the superior oblique muscle the eyeball affected is rotated along with the head. In this way the two eyes are not directed to the same point and a double vision occurs.

Fifth. The trigeminales. The fifth pair of nerves, the *trigeminales*, contain both motor and sensory fibers. They arise from the medulla each in two roots, the smaller of which contains the motor fibers which arise from centers in the floor of the fourth ventricle, while the larger is sensory. This larger root before joining the motor one passes through the large *Gasserian ganglion*. The sensory fibers

arise in a number of scattered places in the medulla, and in this way are brought into direct communication with quite a number of different centers and fibers. After the passage of the sensory branch through the Gasserian ganglion it unites with the motor branch to form the main trunk. This trunk, however, soon divides into three main branches, hence the name of the nerve, which in a general way are distributed as follows: *a.* The *ophthalmic* branch going to the muscles and skin of the forehead and upper eyelid, and the mucous membrane of the nose. *b.* The *superior maxillary* branch innervating the skin of the temples, the cheeks and the angle of the mouth and upper teeth, and within the mouth the mucous membrane or pharynx and soft palate. *c.* The *inferior maxillary*, distributed to the side of the head, the external ear, the skin of the lower part of the face, the lower teeth, the salivary glands, the top of the tongue and the muscles which move the lower jaw in the process of mastication.

While anatomically it is thus divided into three branches physiologically it contains quite a number of different kinds of nerves as follows: (1) Sensory nerves. It is the sensory nerve for the dura mater, for the skin of the entire face, for the orbit of the eye as well as the ball of the eye, for the nose, the mouth, the top of the tongue, the gums, the teeth, the surface of the ear and the auditory meati. In a word, by means of this nerve the sensation of touch is made possible in all the regions mentioned. (2) Motor fibers. It innervates the muscles of mastication, a muscle of the soft palate and the tensor muscle of the middle ear. (3) Secretory fibers to the lachrymal glands, arousing these to the secretion of the tears. (4) Gustatory nerves which are distributed to the tongue. This function is denied by some observers, but it is probable that the sensations of sweet and sour at the tip of the tongue are carried by this nerve. (5) Vaso-motor fibers for the blood-vessels of the eye, the gums and the tongue, by means of which the vascular supply of these structures is to a certain extent con-

trolled. (6) Reflex nerves; that is, nerve fibers which by a reflex action bring about the involuntary closing of the eyelid, such as winking, or which cause coughing and sneezing, or the involuntary movements of swallowing when the soft palate is stimulated. (7) Fibers which in a reflex way bring about not muscular contractions, as in number 6, but secretions of saliva or tears, occasioned by the stimulation respectively of the mucous membrane of the mouth or an irritation of the conjunctiva of the eye.

Sixth. The abducentes. The abducentes nerves arise from the medulla and are distributed to the external recti of the eyes controlling their movements. The sectioning of this nerve causes a turning of the affected eyeball inwards.

Seventh. The faciales. The faciales or facial nerves arise on the floor of the fourth ventricle and are distributed mainly to the muscles of the face. It is, therefore, almost wholly a motor nerve and is of special importance from the fact that it is the nerve which controls the muscles of expression and mimicry.

Eighth. The acoustici. The nerves acoustici or auditory nerves have their origin in centers in the floor of the fourth ventricle of the medulla and innervate the inner ear. They are sensory and carry to the brain the sensations of sound.

Ninth. The glossopharyngeals. The glossopharyngeal nerves are the nerves of taste and are distributed mainly to the posterior portions of the tongue. Fibers, however, reach the tip of the tongue as well, which fibers are believed by some physiologists to cause the sensation of bitter at this point. The sensations of sweet and sour are by these same investigators referred to the trigeminal nerve. On the back of the tongue, however, the glossopharyngeal nerves are able to carry sensations of sweet and sour as well. They also innervate the mucous membrane of the back of the nose and the pharynx. They contain a few motor fibers for certain muscles of the pharynx, and send to the

parotid gland the nerves which control the secretion of the same.

Tenth. The vagi. The vagi or pneumogastrics are the longest of the cranial nerves and their distribution widest. They send branches to the pharynx, gullet, larynx, wind-pipe, lungs, heart, stomach, and even reach the solar plexus in the mesentery. They contain: *First.*—Motor fibers for the muscles of the pharynx, œsophagus and larynx, for the muscular coat of the stomach and the muscles of the principal portion of the small intestine. *Second.*—Inhibitory fibers for the heart. *Third.*—Sensory fibers for the throat, the œsophagus and lungs. *Fourth.*—Reflex fibers which affect the process of inspiration and expiration. *Fifth.*—In man, finally, it contains the depressor nerve (separate in the rabbit) which runs from the heart to the brain and carries sensory impulses to the brain. This depressor figures integrally in the vascular supply of the body.

Eleventh. The accessorii. The spinal accessory nerves in reality arise from the cervical portion of the spinal cord, but run into the skull alongside of the spinal cord, receiving a few fibers from the medulla and then pass out with the pneumogastric nerves. Each gives off a branch to the pneumogastric nerve, while the main portion of the trunk is distributed to the muscles of the shoulder.

Twelfth. The hypoglossi. The hypoglossal nerves are the motor nerves of the tongue and innervate all of the muscles of the same. They carry, however, a few sensory and vaso-motor fibers to the tongue. This nerve is of especial interest in the consideration of the process of mastication, and better still in the production of articulate speech.

The Sympathetic System.

The sympathetic system consists of two chains of ganglia lying alongside the backbone and easily visible when the chest and abdominal viscera are removed. Each chain consists of twenty-four ganglia. In the coccygeal region the two chains meet in a median-placed ganglion, making,

therefore, the total number of sympathetic ganglia twenty-four pairs and one; that is, forty-nine ganglia. The ganglia on each side are connected with each other by means of nerves, while the first ganglion in the cervical region is connected in turn with the brain.

In addition to the connections which each ganglion has with the one preceding and the one following, two other nerves arise from it. One of these is the *communicating* branch already referred to in the description of the spinal cord, a branch by means of which the sympathetic ganglion is anatomically connected with the spinal cord. The other is the visceral nerve proper, the nerve trunk distributed to the viscera, carrying to the same the impulses of this central ganglion, or conveying to these ganglia impulses from the viscera. A very important nerve of this kind is the sympathetic nerve which reaches the heart and is already familiar as the cardio-accelerator. The visceral branches of a number of abdominal ganglia unite to form a common nerve trunk on each side called the *splanchnic* nerve. This nerve is distributed to the abdominal viscera through the solar plexus in the mesentery.

The term sympathetic is a rather unfortunate one, as it frequently leads to the impression that it is mainly concerned with phenomena to which the somewhat vague term of sympathy is applied. That, to use a stereotyped expression, it keeps one part of the body in sympathy with another. Such an expression is, of course, from a scientific standpoint perfectly meaningless. If the term "visceral" system could be generally applied to it this misinterpretation might be avoided, while at the same time the term "visceral" would give a clue to the function of this system which is in a general way concerned with the physiological activities of the visceral organs.

General Histology.

Having in the previous paragraphs called attention to the systems as a whole and their relation to each other, the

next step is to study in detail the individual units of which these systems are composed.

The unit by the multiplied arrangements of which the entire structure of the nervous system is built up is called the *neuron*. A neuron is a nervous cell together with the nerves running out from it. By this name, therefore, is included not the nerve cell merely, but the nerve fiber as well. It has the advantage of doing away with that arbitrary distinction between nerve cells and nerve fibers, and gives emphasis to the fact that a nerve cell with the fibers springing from it is a unit physiologically as well as anatomically.

But the value of this name is further increased by the fact that all the neurons in the entire nervous system are supposed to be distinct and independent anatomically and possibly to some extent physiologically. A neuron is to the nervous system what a single citizen is to the state. In fact, recent researches show that the different neurons of the body are not in direct anatomical continuity, but that each is an anatomical entity, and that impulses from one neuron to the other can be sent only by having one neuron act as a stimulus in arousing a new impulse in the second. It is not the simple original impulse that can reach the second neuron, any more than in two persons joining hands is it the pain experienced by one that is transmitted to the other. The first as a stimulus must reproduce the same pain in the second anew. The relative arrangements and the superposition of the various neurons of the central nervous system will be discussed further on in this chapter, it being the point here to treat of their general histology merely.

Neurons.

One of the most remarkable things about a neuron is usually its size. While there are neurons lying within the central nervous system only a few centimeters or less in length, there are, on the other hand, neurons having a length of several feet. Such neurons, for instance, as reach from the cortex of the brain to the lumbar cord, or still

others reaching from the spinal cord to the ends of the extremities. Anatomically neurons are classed on the basis of the number of nerves issuing from the cell body. A nervous cell with a single nerve fiber issuing from it is spoken of as mono-neuric. These mono-neuric cells are, however, physiologically really di-neuric, the single nerve containing passages leading towards the cell and away from

it, and so being practically the same as two separate nerves. The usual type is the di-neuric neuron.

More than two nerves, however, may arise, in which case the neuron is spoken of as poly-neuric. Illustrations of di-neuric neurons may be found in such ganglia as the spinal root ganglia, in which a nerve runs to each cell body and a second nerve away from it. Usually one of the fibers or extensions of the cell body becomes a typical nerve, while the other branches sub-divide repeatedly and form a perfect network of smaller fibrils reaching out in various di-

Fig. 138.—A POLY-NEURIC GANGLION CELL.
(After Gegenbaur.)

Dotted line indicates the main axis-cylinder.

rections. Such branched terminations are spoken of from their resemblance to trees as *dendrons*. These dendrons do not reach to distant points like the nerve does to skin, muscles or sense-organs, but seem to terminate among the neighboring cells and it is believed that impulses from one cell to another are carried by dendrons of these contiguous nerves.

A neuron, therefore, consists essentially of two parts; the cell body and its extensions into nerves and dendrons.

The cell body is usually much larger than that of other cells in the body and is composed of granular protoplasm contain-

Fig. 139.—TWO CORPUSCLES OF PURKINJE FROM THE CEREBELLUM SHOWING THEIR INVESTMENT WITH DENDRONS FROM CELLS OF THE OUTER GRAY MATTER. (After Ramon y Cajal.)

a, axis-cylinder of corpuscle of Purkinje; *b*, network of dendrons.

ing a relatively large nucleus. The cell body is really the center of energy. We must imagine that here, in some chemical way no doubt, energy is liberated which takes the form of nervous activity. That such a breaking down of the substance of nerve cells occurs when they are being stimulated has been satisfactorily proved by experiments in which nerve cells were subjected to long continued stimuli, then examined with a microscope and compared with similar cells not so stimulated. Such stimulated cells shrink in volume, and in the plainest way indicate a severe loss of their substance. The nucleus becomes much smaller. Similar observations have been made on old nerve cells. Here, too, the cell body becomes shrunken and the nucleus practically disappears. Sometimes the cell body may disappear altogether.

The Nerves.

While in a direct sense the term "nerve" might include the dendrons it is more usually referred to the main fiber leading from the cell to muscle, skin, sense-organ, or other neurons. If such a nerve be examined a little distance

away from the center from which it originated, it seems in a fresh condition almost homogeneous, but when allowed to stand or treated with proper re-agents it soon resolves itself into three structures.

Fig. 140. — MEDULLATED NERVE-FIBER TREATED WITH OSMIC ACID. (After Key and Retzius.)

E, node of Ranvier; K, nucleus of medullary sheath. Primitive sheath and axis-cylinder also show.

Axis-Cylinder. Running through the center of the nerve fiber as a continuation of the nerve cell itself is the axis-cylinder. This is the real nerve matter of the fiber, and is the only one that is really physiologically concerned in the carrying of nervous impulses. In fact, the two other coats may sometimes be absent altogether, but an axis-cylinder can never be absent.

Medullary Sheath. Surrounding the axis-cylinder is a thick whitish-looking coat called the medullary sheath. This medullary sheath seems interrupted at intervals of about one-twenty-fifth of an inch, which interruptions are called the *nodes of Ranvier*. The medullary coat between two consecutive nodes contains a large nucleus and gives evidence that this inter-node is of cellular origin. Chemically the medullary coat consists of a substance called myelin, a substance somewhat akin to that derived from certain connective tissues.

Primitive Sheath. Around the medullary coat in turn is a thin epithelial coat called the primitive sheath or *neurolemma*, or by others the sheath of Schwann. The medullary coat ceases near the cell

from which the axis-cylinder arises, but the primitive sheath is usually continued over the cell body itself. This sheath further dips down into the nodes of Ranvier.

Two opposing views are prevalent as to the nature of the axis-cylinder. According to one view this cylinder consists of a bundle of still finer fibrillæ, too small to be resolved by the microscope, and along these fine fibrillæ the nervous impulses are supposed to pass. The presence of many such fibrillæ in a single axis-cylinder would explain how a single nerve fiber might branch near its termination, as many do. By others the axis-cylinder is looked upon as a tube of nervous plasm, through which the nervous impulse finds its way, and the branching of the nerve fibers is explained in the same way as the terminal branchings of a water-main.

The medullary sheath forms soon after the appearance of the axis-cylinder and arises from certain cells which surround the axis-cylinder much like a string of spools would surround a wire passing through them. The substance of these enclosing cells after they have elongated is changed into myelin, retaining, however, its nucleus. The divisions between contiguous cells is still indicated by the nodes of Ranvier.

While the matter of origin of the medullary sheath is, therefore, fairly clear we are almost entirely at sea for its physiological explanation. That it serves as a kind of insulation for the nervous impulse somewhat like the silk around a copper wire seems hardly true. There is nothing to warrant such a belief. That it may serve as a protection against changes of temperature, and possibly even in a mechanical way, may be true in some cases but would hardly explain the existence of a medullary sheath in the brain or spinal cord itself where fluctuations of temperature certainly do not occur. The statement that nerves do not become functional until the medullary coat is developed does not necessarily mean that the function depends upon this coat. It may simply mean that the axis-cylinder becomes functional about the same period that the medullary sheath

appears. Until further light, therefore, is thrown upon the subject we must look upon this coat as practically unexplained.

Gray Fibers.

Not all nerve fibers possess the medullary coat. The majority of the fibers of the sympathetic system are devoid of it as well as a number of cerebro-spinal nerves.

As the medullary coat is white it gives when present the white appearance to the fiber, and for this reason medullated fibers are frequently referred to as white fibers. The absence of the coat, however, allows the gray color of the axis-cylinder to appear, and for this reason non-medullated fibers are usually referred to as gray fibers. It is well to bear in mind, however, that this is a purely arbitrary distinction depending wholly upon an accidental covering and refers in no way to differences in the nervous matter itself.

Nerve Trunks.

Nerve fibers do not as a rule run singly, but are collected into large bundles familiar as nerve trunks. Examples of such nerve trunks may be the sciatic nerve or optic nerve; in fact any of those whitish threads which in ordinary dissection appear as nerves. Such trunks are easily recognized as nerve trunks by their whitish appearance; but this whitish appearance is really due to the connective tissue which is wrapped around the enclosed fibers. A cross-section of a nerve trunk would reveal about the following general arrangement:

The individual nerve fibers are grouped in from one to many definite bundles called *funiculi*. Each funiculus is closely invested in a coat of connective tissue called the *perineurium*, while branches from this perineurium extend into the funiculus supporting more or less completely the individual fibers and forming the *endoneurium*. These funiculi are then together wrapped in a common coat of connective tissue passing all around them and between them called the *epineurium*. Through these connective

tissue coverings blood-vessels and lymphatics find their way as through other tissues. Along the course of the nerve

Fig. 141.—SECTION OF A NERVE TRUNK (HUMAN). (After Schäfer.)

ep, epineurium; *per*, perineurium; *end*, endoneurium; *v*, blood-vessels; *f*, fat cells stained with osmic acid.

trunk funiculus after funiculus is given off as a separate branch, and finally the individual funiculus is separated until at the end of the nerve trunk this separation is extended to the nerve fibers themselves.

The Development of Nerves.

One of the most interesting chapters in embryology is the development of the nervous tissues and the organs derived from them. Such study shows that the nervous cells are derived from peculiar cells called *neuroblasts*, which cells by their amœboid movements are able to place themselves in definite positions through the body and then later, by a kind of polarization, are able to determine the direction of the nerves issuing from them. When one is re-

minded of the innumerable number of nerve cells composing the nervous system, of their intimate inter-relation, and yet at the same time of the definite way in which they are connected by their fibers, one can appreciate the precision with which these primitive neuroblasts must have distributed themselves while determining their direction of growth. In fact, there are not lacking physiologists who believe that forms of nervous derangement, from insanity downwards, are due to possible accidental misplacements and malformations of these primitive neuroblasts.

A second interesting point concerning these neuroblasts is that they do not increase in number after about the third or fourth month of foetal life, and that the entire development of the nervous system following that is due to an expansion of already formed neurons and the establishment of more and more complicated channels of connection.

Possibly the most important fact from a teacher's standpoint to remember, is that the development of these channels of association, these anatomical connections between different neurons, is not completed until up to and even past maturity, and explains the physiological impossibility for the existence of nervous or mental faculties in the young which later on will naturally appear.

The Regeneration.

When a nerve is cut, the end of the nerve fiber severed from the cell body to which it belonged disintegrates, and a new nerve fiber to innervate the place of the old arises as an outgrowth from the stump of the end in connection with the cell. If, however, the severed ends of such a nerve be connected they seem soon to have grown together. This growing together does not, however, affect the axis-cylinder, for the axis-cylinder grows down through the coats of the old nerve not unlike the growing of a rootlet through the soil. In this growth it is no doubt guided by the path of the old fiber itself, with the medullary coat and primitive sheath of which, contact seems to have been made.

Such a regeneration of fibers does not differ in any way from the manner in which nerve fibers arise in the embryo. The spinal nerves grow out from the spinal cord and penetrate further and further until they finally reach their intended terminations. The optic nerve (together with the retina) is a direct outgrowth of the brain. The auditory nerve is a growth from the brain, which finally reaches and connects with the developing ear.

Neuroglia.

In the brain and spinal cord where the neurons are closely packed they seem to be supported and held in place by a peculiar kind of connective tissue differing entirely from that which supports other tissues. The supporting tissue here consists of large, many-branched cells, looking very much indeed like nerve cells. The many branches of these cells seem to connect and form a supporting mesh-work for the more delicate nervous tissue. These supporting cells and the network which arises from them are spoken of as the neuroglia. These cells are not connective tissue cells, but are in origin related to the nervous cells, having been derived from the same primitive source. In sections of the spinal cord these cells may be easily mistaken for nerve cells, differing, however, from them in the absence of all nervous functions and so, of course, anatomically in the absence of nerves.

GENERAL PHYSIOLOGY OF THE NERVOUS SYSTEM.

Before going into the physiology of special portions of the system it is desirable to treat of those physiological properties which all nervous tissues have in common. In fact, the specific physiologies of the special portions are due more to the origin and distribution of the nerves than to any physiological difference in their activities.

The general physiology of a nerve may be summed up in the statement that it is to convey a nervous impulse. This impulse may arise either in the cell of which the nerve is a

continuation, and from this be carried to muscle or gland, or else in some sense-organ to be carried inwards to the appropriate center. This brings up the question, in what manner a nerve may be stimulated to transmit such impulses.

Nerve Stimuli.

In the laboratory it is possible to stimulate a nerve artificially in the following ways:

1.—*By Mechanical Stimuli.* A tap, a pinch or blow on a living exposed nerve excites it and is the occasion of an impulse through the nerve. A familiar illustration of this is found in striking the crazybone at the elbow, which is in reality striking the nerve at this point. The blow occasions an impulse which runs to the brain, and by the brain is referred, although erroneously, to the fingers.

2.—*Thermal Stimuli.* Sudden change in the temperature excites the nerve, be the change upward or downward. If this change, however, is very gradual, the nerve seems to be able to accustom itself to the change and no direct impulse arises.

3.—*Chemical Stimuli.* Quite a number of substances chemically alter a nerve fiber and so stimulate it. Thus immersing the end of a nerve in a strong solution of common salt excites it. Here, too, if such a nerve be placed in a very dilute solution and this solution then gradually made more concentrated no excitation follows.

4.—*Electrical Stimuli.* One of the most satisfactory ways to stimulate a nerve in experimental physiology is by means of the electrical current. An electric shock passing through a nerve fiber at any part along its course powerfully excites it. Even a sudden change in the strength of the current through a nerve excites it. A steady current, however, has no effect, but when such a current is suddenly broken, the sudden disappearance of the current acts as a stimulus.

The explanation of all these stimuli lies in the *suddenness* with which any change is brought about in the nerve

fiber, be this sudden change electrical, thermal, mechanical or chemical. Of course the stimuli so far enumerated are all artificial stimuli which in the normal physiology of the body are never called into play. The natural nerve stimuli are of two kinds:

First, stimuli which arise in the nerve centers in a way so far entirely unexplained. These are stimuli which are produced in the nerve cells themselves and by these sent out along the fibers. Such stimuli are those produced by the cells of the cortex of the brain, which produce the contraction of the fingers or toes. They may be spoken of as central stimuli. These are always called into play in the production of motor impulses.

The second kind is peripheral stimuli which are best exhibited in the organs of special sensation. Thus in the eye, light in some way excites the optic terminations in the retina. In the ear vibrations in the cochlea excite the auditory hairs on the basilar membrane, while on the skin generally, foreign bodies in their effect upon the tactile corpuscles usually occasion a stimulus interpreted in the mind as sensations of touch.

These peripheral stimuli are, however, not limited to the special sense-organs. Such stimuli may originate in any part of the body. In the stomach the presence of food may produce a stimulus which is carried to the brain, and there in a reflex way translated into a motor impulse to move the muscles of the stomach. In fact, it will be pointed out that the special sense-organs are nothing more than contrivances by means of which stimuli which are too feeble to excite nerves in general are so manipulated in a specially constructed sense-organ as to make possible such an excitation.

Do Nervous Impulses Differ Among Themselves?

Some nerves carry motor impulses, others tactile impulses, still others visual impulses, and the question naturally arises do these impulses differ *inter se*?

The older physiologists entertained the view that the different results produced by different impulses were due to

these impulses themselves. That the sensation of sight was produced by the optic nerve as such, and that a muscle contracted in obedience to a peculiar motor nervous impulse. Soon after, this very sweeping distinction was narrowed down to a division into two kinds of nervous impulses—those which produced motion and those which resulted in sensation. That such impulses were inherently different was occasioned by the observation that when a motor nerve was cut and the end connected with the muscle pinched a contraction followed, but that when the central end was pinched no sensation followed. While on the other hand, when the sensory nerve was cut, no motion resulted upon the distal end being pinched, but a decided sensation followed the stimulation of the central end. There is, however, every reason to believe that these impulses do not differ among themselves, but that the difference in results is due to the different endings which these nerves have. A sensory nerve cannot produce motion for the simple reason that it is not in contact with muscles, while a motor nerve cannot produce sensation for the simple reason that it does not run to centers where such sensations are received.

That all nerve fibers are physiologically alike seems further evident from the following reasons: (1.) A microscopic and chemical analysis shows no differences whatever between the nerve fibers. (2.) All nerve fibers carry impulses in both directions. For instance, when a nerve is stimulated in the middle of its course the impulse runs from this point towards both ends with equal facility and rapidity, and this is true whether the nerve be a sensory or a motor one. (3.) The nature of the nervous impulse seems to be the same no matter what may have been the occasion for its excitation. Thus a nervous impulse resulting from the pinching of a nerve is, as far as we are able to detect, perfectly identical with the impulses produced by an electric current, or even by the natural end organ itself. Thus, the impulse which runs along the optic nerve, regularly occasioned by light falling on the retina, is identical with the

impulse carried by the optic nerve when this nerve is electrically stimulated.

Having now seen the oneness of all nervous impulses the question arises, what is its nature?

The Nature of a Nervous Impulse.

Soon after the electrical current became known many attempts were made by the older physiologists to explain nervous impulses in terms of electricity. The analogy between the nerves of the body and a system of telephone or telegraph wires was too striking to be overlooked. But all attempts to explain one in terms of the other have so far been a failure. That a nervous impulse is not of an electrical nature is evident for several reasons: A nervous impulse will not travel along a dead nerve, or even a nerve which has been numbed by cold. A nervous impulse will not pass across a cut in a nerve, even though the two cut ends be fastened together. Surely if nervous impulses were of an electrical nature they would still pass in spite of these difficulties. It has been possible to measure the rate at which nervous impulses move. This measurement was first accomplished by the physiologist Helmholtz. The experiment is simple enough. A muscle was cut out from the body of an animal and a long portion of the nerve leading to it left intact. The muscle and nerve preparation were so arranged that the time could be very accurately measured between the moment when the nerve was stimulated and the moment when the muscle contracted. The nerve was now stimulated close to its insertion in the muscle, and the time that elapsed between the stimulation of the nerve and the contraction of the muscle carefully observed. Next, the nerve was stimulated at its further end, that is, the nervous impulse had now to go further through the nerve than it did in the first instance. Again the time elapsing between the moment of stimulation and the moment of contraction was noted. The difference in time was of course the extra time needed in the second case for the impulse to traverse the added length of nerve.

In such a simple way the experiment proved the rapidity of a nervous impulse to be 28 meters; that is, a little over 92 feet per second. These, however, are the figures for the motor nerves of the frog. The rate of transmission is somewhat faster in the motor nerves of warm-blooded animals, and is here probably not far from 100 feet per second.

Experiments on sensory nerves are, of course, not so easy, but there is reason to believe that the speed of the impulse is about the same as that of the motor nerves. Such a speed of about 100 feet per second is, of course, exceedingly slow compared with the rate of transmission of an electric impulse, and would seem to settle conclusively the difference between the two.

That a nervous impulse is of a chemical nature seems disproved by the fact that no exhaustion occurs in a nerve in the transmission of this impulse. It has been possible in experiments to send long continued repeated impulses along a nerve without noticing at the close of the experiment that the nerve had been thereby exhausted. Such stimulation of course commonly exhausts the muscle with which the nerve is connected, or if a sensory nerve the centers to which it goes, but in a very slight degree, if any, the fiber itself. If it were a chemical change it would be difficult to see how an exhaustion caused by the chemical disintegration could be avoided. The only explanation left, therefore, seems to be that it is some kind of a molecular change which travels along the fiber, a molecular change, however, of the nature of which we are still wholly at sea.

Several things about the impulse are known. Its rate of speed is about 100 feet per second. We also know that the nervous impulse is in the nature of a wave, which is about 18 millimeters in length. This is a little over seven-tenths of an inch.

The wave-like nature of the impulse is evident from, and can be measured by, a peculiar electrical wave which runs along the nerve fiber with the nervous impulse, which electrical wave is easily detected by means of the galvano-

meter. If the electrodes of a sensitive galvanometer be placed on a nerve and an impulse then be transmitted along the nerve the needle of the galvanometer will be deflected in such a way as to reveal the presence of a current at the moment the nervous impulse is passing. This current has been called the *current of negative variation*. This wave of variation travels, of course, with the same speed as the impulse, and the time it takes to pass a certain point can be easily determined. One has simply to note at what instant the deflection of the needle begins and the instant it ceases. Measurements of this kind have shown that the wave takes only about .0007 of a second to pass. Thus, knowing its rate of speed and the time consumed in passing a given point, it is a simple mathematical calculation to show that it is a little over seven-tenths of an inch in length. The needle further indicates that at first this current is very feeble, then rises to a maximum, then gradually falls and disappears.

This wave of negative variation is but a result of the nervous impulse and is caused by the molecular changes in the nerve fiber as the impulse proceeds, much as in the running of a train there might be along the rails accompanying the train currents of electricity caused by the friction of the running wheels, which current might be easily detected by a galvanometer even though the train itself should be invisible.

KINDS OF NERVE FIBERS.

Any real division of nerve fibers is obviously possible only on the basis of the organs or centers with which they are connected. On this basis nerve fibers are divided into two classes, the first called the *afferent* or *sensory* fibers, the second the *efferent* or *motor* fibers. The terms sensory and motor are, however, not very fortunate ones, as there are some afferent fibers that never carry sensations which reach consciousness, while many of the motor fibers carry impulses which do not reach muscles. A more detailed classification is usually made as follows:

First.—Sensory fibers which, when stimulated, produce sensations of which we are conscious. The best illustrations of these sensory fibers are the nerves of the special senses.

Second.—Reflex sensory fibers which when excited carry sensations to the brain, which, however, do not usually reach consciousness, but in the lower brain centers give rise to motor impulses without the intervention of the will. The best illustration of these possibly is the narrowing of the pupil when subjected to a strong light. Some of these reflex sensory fibers may occasionally come within the reach of consciousness. Many of them, however, are entirely outside of it. Such are the reflex sensory fibers, for instance, which carry the sensations from the stomach, when food reaches it, to the brain, to be there translated into impulses leading to the active secretion of the glands of the stomach or to the contraction of its walls.

Third.—Inhibitory sensory fibers; fibers which when stimulated carry sensations to nervous centers which seem to inhibit their action. So, for instance, the biting of the lips may succeed in preventing a spasm of sneezing.

The three classes so far mentioned are included under the usual term of sensory fibers. Of the efferent nerve fibers physiologists usually make the following classes:

Fourth.—Motor fibers proper, those which innervate the muscles and produce their contractions. Under this head are included not only the nerves which run to the skeletal muscles, but also the nerves which run to some of the involuntary muscles, especially the vaso-motor fibers which run to the muscular coats of the blood-vessels.

Fifth.—Secretory fibers. These are fibers distributed to the cells which constitute the various glands of the body and which govern their secretion.

Sixth.—Inhibitory nerves which inhibit muscular action, the clearest example of which is the inhibitory nerve of the

heart, the excitation of which slows the rate of beat in this organ.

All the nerves so far mentioned are nerves which run to the periphery. There are, of course, in addition to these, many nerves which never get beyond the central nervous system, but which run in this for their entire course and serve to connect the various centers within the same, carrying between these centers impulses similar to those carried by peripheral nerves.

THE GENERAL PHYSIOLOGY OF NERVE CENTERS.

We are in this discussion not yet concerned with the special functions of the various nerve centers, but merely with those phenomena which apply more or less fully to all nerve cells. In this general way nerve cells or collections of the same into ganglia, are classed as follows:

1.—*Automatic Centers.* These are centers which do not seem to depend on some specific external impulse to arouse them, but which seem to act more or less independently of all such stimuli. The best illustration is possibly that of the higher centers in the brain which we are wont to designate as the centers concerned in free volition. In addition to these higher psychic centers there are lower automatic ones, such, for instance, as the automatic centers in the heart causing the beat of the same entirely independently, so far as we know, of external stimuli. Such automatic centers may, of course, be aroused, and within certain limits, controlled by outside stimulation, but such outside stimulation need not be the invariable occasion for their acting.

2.—*Reflex Centers.* These are centers found mainly in the spinal cord, but present also in the brain, to which sensory impulses are carried, and which as a result of such impulses originate motor impulses in harmony with these sensations. When working normally these reflex centers are groups of cells which co-ordinate the incoming impulses and the outgoing impulses to produce purposive results. When a person unknowingly touches a hot stove with his

fingers the sensation produced by the burning is carried to the reflex centers in the spinal cord and by these reflex centers motor impulses are sent out to remove the hand. These motor impulses are in harmony with the incoming impulses and are intended for specific purposes.

The medulla oblongata contains many of the higher reflex centers. Such, for instance, as the reflex centers occasioning respiration; the reflex center controlling the general vascular supply; the reflex center regulating the general temperature of the body, and others. In the brain are reflex centers co-ordinating sensations and motions without the intervention of consciousness, while in the spinal cord are quite a number of centers concerned in the manipulation of the trunk and limbs.

3.—*Junction Centers.* In addition to the automatic centers which seem to have the power to originate nervous impulses and the reflex centers which are able to co-ordinate sensations and movements without appealing to consciousness there are a number of ganglia, the function of which seems to be entirely that of a relay station or junction center. For instance, the spinal root ganglion is in all probability nothing more than a relay station serving merely to act as a center of nourishment and strength to the nerve fiber itself, and having nothing to do with the impulses traversing it save to make more possible their transmission. Much as in a system of telegraph wires there are relays of batteries, from time to time, concerned only in making the transmission of the impulses originated in other ways possible. In still other cases nerve centers seem to be mere junction centers; that is, centers of distribution. A single impulse running into such a center will be distributed through the many cells in that center and flow out of it increased many fold. The ganglia in the mesentery and alimentary canal probably serve in this manner and make possible that the few impulses reaching these organs will be finally multiplied and distributed as to reach each individual muscle fiber composing them.

Having now treated of these general points which apply more or less fully to nerve cells wherever found, the question naturally follows, what are the special functions of the various nerve centers found in the body, and what are the specific paths of the fibers connecting these centers with each other and with the periphery? We are therefore concerned next with the finer architecture of the central nervous system.

*THE FINER ARCHITECTURE AND THE SPECIAL PHYSIOLOGY
OF THE CENTRAL NERVOUS SYSTEM.*

Perhaps in no department of the field of physiology have the views been so materially modified of late as in the conceptions of the structure of the central nervous system. Recent studies of such men as Golgi, Van Gehuchten, Ramon y Cajal, and others have completely changed our notions of the fundamental structure of nervous tissue. It is now believed, and with the best of evidence, that the entire nervous system is made up of separate and distinct units called neurons, a general description of which occurred in the preceding pages.

These neurons are practically all alike, at least anatomically, unless we except those of the cerebrum to which we are at present obliged to assign psychic functions. No neuron is connected with any other neuron directly, but the impulse from one to another is effected at the point where they lie either close together or in possible direct contact. The old notion of a continuous network of nerve fibers pervading the entire system is done away with.

In such separate and distinct neurons the cell body is the physiological and nutritive center. To this center impulses are carried by some of its branches, and from it in turn impulses are carried out by other branches. A section of any of the branches or nerves of such a neuron at once results in the death of that end of the nerve severed from the cell body. It is the purpose in this paragraph to show in an elementary way but with some special detail the manner in which these neurons are arranged and superposed.

1.—*Arrangement of the Motor Neurons.* The arrangement of the motor neurons is about as follows: In the cortex of the brain near the fissure of Rolando are certain large cells which give off small branches in various directions and usually one long branch, the nerve fiber proper. This extends from the cortical region through the crus cerebri of its side, and in the medulla crosses to the opposite side of the cord. It then descends through the spinal cord in the so-called lateral column of that side, commonly designated the *crossed pyramidal tract*, and finally enters the anterior horn of the spinal cord and ends there in the fine network of dendrons, which closely invest similar short dendrons of the motor cells of the anterior horn. These motor cells are the cell bodies of the second neurons, and their nerve fibers extend from the anterior horn through the anterior roots of the spinal nerve to the muscles in question. In other words, from the point in the brain where the volition arises to the point in the muscle where the contraction is produced there are two neurons, one reaching from the brain, where the cell body is, through the cord to the anterior horn, the second neuron reaching from this point to the muscle. This is the usual course of the motor neurons.

A second course is, however, possible. Many motor fibers arising in the cortex do not cross to the opposite side in the medulla, but descend the spinal cord on the same side along the *anterior tracts*, and then along in the course of the spinal cord cross to the other side, through the anterior commissure of the cord. It will be seen, however, that all these motor fibers finally reach the opposite side of the cord, and the difference between the fibers in the lateral column and those in the *direct pyramidal tract* is a secondary one. The fact that some cross in the medulla and others in the cord further down is no real difference. In either case these neurons from the brain end in the anterior gray horns, and there connect with the second motor neurons which reach to the muscles. The general arrange-

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Fig. 144.—DIAGRAMMATIC CROSS-SECTION OF THE SPINAL CORD SHOWING THE MOTOR, RED, AND SENSORY, BLUE, PATHS. (After Van Gehuchten.)

1, crossed or lateral pyramidal tract; 2, direct, or anterior pyramidal tract; 3, posterior sensory columns; 4, direct cerebellar tract; 5, antero-lateral ground bundles; 6, crossed sensory, or antero-lateral ascending tract.

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Fig. 142.—DIAGRAM OF THE MOTOR PATHS SHOWING THEIR MANNER OF CROSSING EITHER IN THE PYRAMIDS OR LOWER IN THE CORD. (After Van Gehuchten.)

ment of this is schematically indicated in the accompanying diagram, in which the reader will find it possible to follow the description of the text.

2.—*The Arrangement of the Sensory Neurons.* The sensory neurons are more complicated, but in a general way here, too, there are two neurons reaching from the sense-organ to the brain. The first neuron has its cell body in the spinal root ganglion. From this body one nerve goes to the touch corpuscles, say of the finger, while from the same body a second nerve fiber runs into the posterior horn of the spinal cord. To repeat: One neuron bridges the distance from the point of touch in the finger to the spinal cord with the cell body of this neuron located in the spinal root ganglion. The endings of this sensory fiber in the cord are in a general way as follows:

As soon as the fiber reaches the posterior horn it divides into an ascending and a descending branch which pass up and down respectively through the gray matter of the posterior horn. From these branches smaller branches called collaterals are given off at right angles. Some of these main branches or collaterals may run into the anterior horns, and there end in capillary dendrons which invest the motor cells

Fig. 143.—DIAGRAM TO SHOW PATHS OF NERVE-FIBERS IN THE SPINAL CORD. (After v. Lenhossék.)

M, voluntary muscle; H, skin of hand; T, touch corpuscle; HW, posterior root spinal nerve; VW, anterior root spinal nerve; PP, sensory nerve; Sp, spinal root ganglion; s, cell body of sensory neuron; m, motor cells in anterior horn; n, motor nerve; e, collaterals of the sensory neuron of spinal root ganglion; a, b, a continuation of sensory neuron c, upwards and downwards through gray matter of posterior horn; Z, a neuron lying entirely within the cord, and by means of the collaterals d, d, connecting opposite sides of the cord.

By reference to the text it will be possible to trace some of the main nervous paths there described.

found here. It is this arrangement of the neurons of sensation and motion which makes the simple reflex actions of the cord possible.

Other branches or collaterals with their dendrons invest cells found in Clark's column. These cells in Clark's column are the beginnings of new neurons which reach from Clark's column in the spinal cord to the cerebellum, the fibers ascending in the *direct cerebellar tract*. In this way sensations are carried to the motor cells of the cerebellum and make the reflex actions of the cerebellum possible.

None of the two paths just mentioned, however, result in conscious sensation. There is a third path which leads to the cerebrum itself. This path is about as follows: The sensory nerves or branches from them, leave the posterior horn of the spinal cord and ascend towards the brain through the posterior columns. Many of these fibers run as far as the medulla. In the gray matter of the medulla, however, their dendrons invest new cells, nerves from which, after *crossing in the medulla*, extend to the cortex of the brain.

While most of the sensory fibers running up the posterior column connect with their second neuron in the medulla, many of them run into the gray matter of the spinal cord before reaching the medulla, and there invest cells the nerves from which then cross to the opposite side of the spinal cord and reach the cortex of the brain. The path for these crossed sensory fibers of the cord is the *antero-lateral-ascending tract*.

An additional sensory path needs mentioning. Some of the branches or collaterals of the sensory fibers may connect with neurons in the gray matter of the cord, which run to the opposite side of the cord and connect with other neurons there. That such paths exist is proved by the fact that when the sensory fibers of one side of the spinal cord are cut sensation is not lost, but seems actually for a little while to be increased. This can, of course, only be explained by assuming that fibers must connect with the opposite or uninjured side of the cord.

With the motor impulses the case is different. When the motor fibers of one side are cut that side is completely paralyzed, even when the other side is left intact, showing that the motor paths are direct.

3.—*Summary of Nerve Paths.* To summarize, then, there are the following sensory paths:

First. The neuron extending from the finger to the spinal root ganglion and from there in turn to the posterior horn of the spinal cord, may run directly to the anterior horn and invest with its dendrons a motor cell there, and so produce the path for the simple spinal cord reflexes.

Second. The first sensory neuron may run not to the motor cells, but to the cells forming Clark's column and invest one of these with its dendron, which cell in turn as a new neuron extends to the cerebellum and makes possible the cerebellar reflexes.

Third. The first neuron or branches of it may connect with a neuron of the spinal cord which runs to the opposite side of the spinal cord and there connects with other neurons. This path makes possible the radiation of sensations to both sides of the spinal cord.

Fourth. The first neuron may connect with neurons running to the cerebrum (*a*) by running up through the posterior columns and connecting with the second neuron in the medulla, which neuron there crosses and goes to the opposite cerebral hemisphere; or (*b*) the first neuron after ascending a short distance through the posterior column enters the gray matter of the cord and there connects with a neuron which crosses to the opposite side of the cord, and in the antero-lateral tract reaches the cerebral hemispheres the same as the neurons which cross in the medulla.

4.—*Where Do the Sensory Neurons End in the Brain?*
A very interesting question now arises, with what do these sensory neurons connect in the cortex of the brain? While this is possibly still debatable ground, it seems very proba-

ble that these sensory neurons with their capillary dendrons at their ends invest the motor cells which form the first neurons of the motor path. If this be true, it gives to these cells the wonderful faculty of not only serving as voluntary motor cells, but as conscious sensory cells. In other words, in these cortical cells the consciousness of sensation as well as the consciousness of volition is located.

5.—*Comparison of Sensory and Motor Paths.* It will be noticed that in the sensory, as in the motor path, there are essentially two neurons between the periphery and the brain. Further, both sensory and motor neurons cross, either in the medulla, or further down in the cord. An interesting difference between the sensory and motor neurons lies in the fact that in one case the cell body of the lower neuron lies

Fig. 145.—DIAGRAM SHOWING THE PATHS OF FIBERS IN THE CEREBRO-SPINAL SYSTEM.

Outgoing arrows indicate motor, incoming arrows sensory fibers.

R, R, right and left cerebral hemispheres; *G, G*, gray matter of mid-brain, optic thalami and upper medulla; *H, H*, lower portion of medulla where the cranial nerves take their origin; *H, H* (at bottom of figure), the gray matter of spinal cord; *1a*, motor nerves; *1b*, sensory nerves; *6, 6*, fibers connecting the hemispheres; *1c*, half-crossed optic fibers; *5, 5*, fibers connecting different portions of same hemisphere; *2, 2*, crossed pyramidal tract; *2', 2'*, direct pyramidal tract crossing in the cord; *3, 3*, sensory fibers, some crossing in the pyramids (others have crossed in the cord, not shown), but all passing through the gray matter *G*. By reference to the text the diagram will be more intelligible.

outside of the spinal cord, in the spinal root ganglion, while in the case of the motor neurons it lies inside of the spinal

cord, in the gray matter of the anterior horns. This difference of position is, of course, physiologically a secondary one.

The sensory cranial nerves find their counterparts of the spinal root ganglia in the sensory ganglia which they possess. Such, for instance, as the Gasserian ganglion of the fifth cranial nerve.

It simplifies the conception of the sympathetic system, to look upon the sympathetic ganglia lying along the spinal cord as a second set of spinal root ganglia containing sensory and possibly motor neurons, which in this case reach from the spinal cord to the viscera, instead of to the body wall and skin as in the case of the spinal root ganglia proper. This conception of the sympathetic ganglia as spinal root ganglia lends a unity to the entire nervous system, doing away at once with the too general notion that the sympathetic system is a special system only incidentally connected with the spinal cord.

THE MEDULLA.

In the medulla the general arrangement of gray and white matter found in the cord is materially varied from for several reasons. In the first place, the decussation of the motor and sensory fibers displaces the gray matter. In addition to that we find here many new centers. In the medulla are located, for instance, the center governing respiration, that governing the temperature of the body, that governing the vascular supply, and others. In addition to that we find here much gray matter, the cells of which are probably the second neurons of sensation just described. Here, also, are a number of centers connected with the nerves of the special senses. The exact location of these centers is omitted from this elementary discussion as being too complicated. There remains, therefore, for further description the arrangement of fibers and centers in the cerebellum and cerebrum.

SPECIAL FUNCTIONS OF THE BRAIN AND CORD.

It was pointed out that the function of the spinal cord is two-fold. First, it serves as a tract along which sensory and motor fibers run that connect the brain with the distant portions of the body. Second, it consists of centers which are concerned in the simple reflex actions. Thus, if a frog be taken and its brain removed, and the toe of such a frog pinched, the leg will be drawn up with almost as much precision as in the case of an uninjured frog. A piece of blotting paper soaked with an irritating solution, such as an acid, placed on his skin will produce a series of the most perfectly co-ordinated movements. If the foot be held firmly and then pinched the frog at first tries to pull away the injured foot and upon repeated failures to accomplish this it will bring into play the foot on the other side to effect his purpose. Here is a case in which the reflexes have become complicated, have called in the opposite side of the spinal cord, and yet are all so co-ordinated as to be directly purposive.

The question whether there are any automatic centers in the spinal cord is still an open one, but the evidence seems to show that it possesses reflex centers only. Instances of impulses which seem to have originated in the spinal cord have generally been traceable to outside influences for their occasion. These outside influences are of course two. First, sensations, carried by the sensory neurons directly to it. In this case a reflex action arises without the intervention of the brain. Second, motor impulses from the higher centers of the brain. These higher impulses from the brain calling into action these motor centers produce the ordinary voluntary movements as we know them.

While most of the reflexes of the spinal cord are natural, that is, inherited, it is possible by training to establish reflexes of a highly acquired character. Much of the quick perception and delicate touch of an artist on most any kind of an instrument is due to the establishment of fine reflexes in his spinal cord. Such an artist is frequently able to re-

act to his sensations without the direct intervention of his brain.

SPECIAL PHYSIOLOGY OF THE MEDULLA.

In the medulla, too, we find reflex centers, but the reflex centers are here of a higher kind. They are still involuntary and largely outside of the control of the will, but are not the simple muscular reflexes of the cord. They are the higher reflexes governing complicated systems in the body. In fact, it may be proper to speak of the reflexes here as the *systemic* reflexes. Instances of the reflex centers of breathing, circulation and temperature have already been noted. In addition to these we find in the medulla some of the simpler reflexes, the sensation occasioning which are derived from the special senses.

THE PHYSIOLOGY OF THE CEREBELLUM.

It is exceedingly difficult to determine definitely the functions of such complicated structures as the cerebrum and the cerebellum. The structures are so delicate and the methods of operation upon them to determine their functions so coarse that it is frequently difficult to argue from cause to effect. One can easily imagine how much progress would be made by an individual trying to understand the workings of a watch by standing off at a distance and firing pistol shots at it and then noting the result; firing first at the hand, then the face of the watch, then spring or case. One can easily see the almost utter hopelessness of ever getting at a complete knowledge of a watch by such rude means, and yet incisions or stimulations, in fact all of the experiments made on the brains of animals have been relatively as rough and inexact as the firing of a pistol into the delicate watch. A few general points are, however, available.

It seems probable that the function of the cerebellum is that of a large motor center to whose jurisdiction are consigned the ordinary *habitual* motions of the body; walking, running, in case of animals, flying or swimming. These motor habits are doubtless acquired painfully and slowly

by the cerebrum, as for instance, in the case of an infant learning to walk or crawl. As they are repeated over and over again they become more and more habitual. They seem to be delegated more and more by the conscious cere-

Fig. 146. — SECTION OF THE CORTEX OF CEREBELLUM. (After Sankey.)

a, pia-mater with contained blood-vessels; *b*, external layer of gray matter; *c*, layer of corpuscles (nerve cells) of Purkinje; *d*, inner granule layer; *e*, medulla.

brum to the lower cerebellum, and in this way the activity of the cerebrum left to higher functions instead of continually wasting its strength in looking after the contraction of the muscles in moving the body.

If, for instance, the cerebellum be removed from the brain of a pigeon the animal sits quietly, seems to be conscious of danger; seems, in short, to retain most of its psychic functions, but is awkward in its walk, stumbles and falls easily, and flies with the greatest difficulty. It has lost control, apparently, of the motions which originally it performed with rapidity and precision. Removals of the cerebellum from other animals have in a general way shown similar results.

Without going into further detail the whole point

may be summed up in the statement that it is the governing center for the general habitual motions of the body. The physiological value of this is at once clear when we remem-

ber that by delegating the control over these complicated motions to the cerebellum the cerebrum is enabled to turn its attention to higher functions.

THE PHYSIOLOGY OF THE MID-BRAIN.

In giving the functions of the mid-brain it is desirable to include the optic thalami, for although these bodies are anatomically classed with the cerebrum they belong physiologically to the mid-brain. The crura cerebri of the mid-brain are, of course, mere bands of fibers connecting spinal cord and brain, so that we have to do here only with the corpora quadrigemina of the dorsal side.

The difficulty of experimenting on these structures, since they are hard to reach without injuring other parts of the brain, makes our knowledge somewhat fragmentary. Enough evidence is, however, at hand to show that the corpora quadrigemina, especially, are great reflex centers between visual impressions and the motor impulses which govern the movements of the eyeballs. Here, without the intervention of consciousness, the visual sensations produce reflexes, by means of which the eyeballs are turned as occasion or necessity requires. Every one is aware that he keeps his eyeballs in constant motion turning hither and thither as one object after another arrests his attention, and yet does all of this without any real conscious intervention. It is only when special points come up demanding special scrutiny that we become consciously aware and in a voluntary way direct the muscular movements of the eye. That visual sensations figure so prominently in all our actions, shows the necessity, or at least the great desirability, of having a reflex center where these many visual sensations may be properly interpreted and reflected in purposeful motor impulses.

But not only do the motor impulses of the eye originate here but the optic thalami and mid-brain seem also to be materially concerned in receiving the visual sensations and reflecting them in purposeful locomotary impulses. It is

an every-day experience that one will go along a path stepping over all obstacles, walking around obstructions, getting out of the way of passers-by or vehicles, stepping carefully sometimes over pools of water, even ascending steps, and yet do all of this without the slightest apparent intervention of consciousness. During all of this time a person may be deeply absorbed in some train of thought, and if he were questioned at the end of his journey about any of the details of the way would be utterly unable to recall even a few. It is of course also evident that nearly all of the motions of the body are guided by the sensations of sight. True an individual may walk or run with his eyes shut and depend upon other sensations, but that is only possible where the individual knows the road to begin with, or is supremely indifferent to accidents. Ordinarily speaking, the visual impressions which never reach consciousness are the guides which determine the motions of the body. These complicated reflexes have their seat in the optic thalami or mid-brain, and for the final execution of some of the habitual movements of the body the cerebellum also comes into play. It needs no special comment to point out what a saving of energy it is to the higher centers of the brain to be relieved from the interpretation of the crowd of sensations pouring in through eye (or ear) and their proper reflection into correspondingly purposeful motor impulses.

It will be pointed out later that the place where visual sensations come into the field of consciousness lies in the occipital lobes of the brain. Here seems to be the curtain of the mind against which the images are projected for direct and conscious scrutiny. But a small proportion, however, of the visual sensations reach this high conscious center. Most of them never get beyond the sub-conscious and reflex centers of optic thalami and mid-brain. An animal whose occipital lobes are removed, and which is therefore consciously blind, is still able to avoid obstacles in its way and prevent itself from stumbling over obstructions by going around them, on account of the fact that the

sub-conscious reflexes referred to are still intact. Such a dog, however, makes no difference between an obstacle, as a dish of food, or a dangerous or threatening obstruction. He is able to make no conscious interpretation, and by his sub-conscious centers both the inviting food before him or the threatening rod are mere obstacles to be avoided lest he should run against them.

Leaving now all of these lower centers of the nervous system we reach finally the cerebrum itself, where, as far as we know, the nerve centers have associated with them for the first time that peculiar property which we are wont to designate as consciousness.

*THE PHYSIOLOGY OF THE BRAIN AND THE LOCALIZATION
OF CENTERS.*

The careful work of such men as Jackson, Hitzig, Fritsch, Beevor, Horsley and Ferrier has enabled us to mark off the physiological topography of the cortex of the brain and to establish for definite portions of the cortex certain specific and definite functions. Their researches have completely disproved the older notion that the entire brain acted as a unit in every brain act; that a sensation, or a volition, or a memory were actions participated in by the entire brain as one structure. We now know that memory is no such a simple thing, but that in certain portions of the brain are stored auditory sensations, in other visual sensations, and so on. We know that in certain portions of the brain the voluntary impulses arise that move the foot; in other definite regions those that govern the movements of the hand. It has even been possible by pathological observations to establish the position of the center of speech. The topography of the brain as given in the accompanying diagram is that now generally accepted.

The position of these centers has been determined experimentally in one or more of the following ways:

First. It not infrequently happens that persons are born possessing certain brain malformations. By the post mortem

determination of these anatomical malformations and their comparison with the observed mental acts, deductions have been arrived at as to the function of the parts affected.

Second. Occasionally a normal brain is pathologically injured either by compression, as in accidents, by inflammation in disease, or by the formation of tumors in certain portions of its structure. It was by noticing the fact that the presence of a tumor in the left frontal lobe of the brain was always associated with the loss of speech that that center was finally localized in that region.

Third. Upon animals it has been possible to cut off certain regions of the brain to note the physiological effects of such excisions. It was, for instance, by the extirpation of the occipital lobes of the brain that the center of conscious vision was definitely located.

Fourth. By stimulation experiments made directly on the cortex of the brain. A new era in brain physiology was ushered in when Fritsch, Hitzig, and later Ferrier, succeeded in producing movements by electrically stimulating certain regions of the cortex of the brain. By subjecting various portions of the cortex to such stimuli and noting what muscles of the body were affected by the motor impulses so originated, it was soon relatively easy to map out the motor topography of the cortex, and it is upon these experiments that the results in the diagram are based.

Fifth. For the determination not only of the centers of the brain, but of the nerve fibers which extend from them, two methods of study suggested themselves. (*a*) In the embryonic development of animals it was found that certain cells and certain nerve fibers developed sooner than others, so that in this way it was possible to give the region and follow the course of certain nerve fibers before neighboring ones with which they might later be confused had developed. (*b*) A method productive of even more results than this was what was called the Wallerian method, or the method of degeneration. It has already been pointed out,

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Fig. 147.—DIAGRAM OF THE VISUAL PATHS. (Modified from Viallet.)

OP. N, optic nerve; OP. C, optic commissure; OP. T, optic tract; OP. R, optic radiations; V. S, visual speech center; A. S, auditory speech center; M. S, motor speech center. A lesion or section at 1 causes blindness of that eye; at 2, blindness of the outer half of each eye; at 3, blindness of the nasal half of that eye; similar lesions at 3 and 3', blindness of nasal halves of both retinas; at 4, blindness of nasal half of one eye and temporal half of opposite eye; at 8, on left side, word blindness

that when the cell bodies to which nerves are attached are destroyed in any way, these nerves at once die to their periphery. By this method it was possible to destroy certain brain centers and thus destroy the entire bundle of nerves leading out from it. This, of course, enabled the observer to determine over what part of the body the nerve centers in question had jurisdiction. It was this method of degeneration that helped materially in giving us our knowledge as we now have it of the courses of the fibers in the spinal cord.

THE PHYSIOLOGICAL TOPOGRAPHY OF THE BRAIN.

1.—*The Motor Areas.* The motor areas of the brain lie along the fissure of Rolando. At the top of this fissure are the motor areas governing the toes. These are followed by motor nerves which govern regions gradually higher up, until at the bottom of the fissure of Rolando we come to those motor areas concerned in the control of lips, larynx and mouth. The proximity of these motor centers to the speech center on the left side is worth noting.

2.—*The Seat of Conscious Tactile Sensations.* But not only are these motor centers concerned in the production of the voluntary impulses. They are also the seat of the sensations which arise in the portions, the motions of which they control. Thus the motor area along the fissure of Rolando governing the muscles of the finger is probably also the center in which the sensory impulses coming from the finger are finally interpreted as conscious sensations. This area ought, therefore, more properly to be called the *motor-sensory* area.

3.—*The Visual Center.* In the occipital lobes the visual center is located. It is of interest to point out here that while for the motor areas the right side of the brain governs the left side of the body, and vice versa, there is not such a complete crossing for the optic nerves. There is, in fact, in the optic nerve only a half crossing. In the right

occipital lobe arise the fibers for the left half of each retina, while from the left occipital lobe the right half of each retina is innervated. This half decussation, of course, occurs in the optic commissure. The destruction of one of the occipital lobes, therefore, produces blindness in the opposite half of each eye.

4.—*The Auditory Center.* Immediately below the fissure of Sylvius, in the upper convolution of each temporal lobe is located the center of hearing. Here are stored away the memories of the meanings of all heard words and sounds. Some investigators give the center for perception of musical sounds as somewhat forward from the place where ordinary sounded words are stored.

5.—*The Centers for Taste, Smell and Speech.* Below the auditory centers in the temporal lobes seem to be located the centers for taste and smell. One of the most interesting of all of the centers, and strange, too, one of the first to be localized, is the center of speech. This lies in the left frontal lobe immediately anterior to the motor areas governing lips, pharynx and mouth. The fact that this center is usually located on the left side is explained by the circumstance probably that most persons write with their right-hand, which is a form of speaking as far as the intellectual part of it is concerned. Persons who have habitually written with their left-hands would be more liable to have the center of speech located on the right side. The interesting question arises, why such a center should be on the one side only? There is no satisfactory reason for this, unless it be that as speech is such a unit, and as its coherency would require such a careful co-ordination of two sides, it would hardly be probable that such could be accomplished from the action of two separate centers. There is the possibility of directing the two eyes to two different objects, as in the case of cross-eyed persons, and the ability thus to see, to some extent at least, double. Similar double sensations are possible with the ear. Double motions from the

right and left side are perfectly natural, but it can be easily seen that coherent speech is a unity which could not easily result from the actions of two separate sources or agencies.

CONSCIOUSNESS.

The question is repeatedly asked in what sense consciousness is a physiological property. This whole point may be dismissed as far as its physiology is concerned by the statement that of its real nature we know scientifically absolutely nothing. Held by some to be merely a high form of mechanical or chemical changes in certain cells, the phenomena of consciousness have been reduced to merely physical phenomena and so robbed of what we know as their free will. Such investigators to be consistent deny that there is such a thing as free will, but that all the multiplied interchanges of sensation and volition are just so many necessary causes and effects. On the other hand, other observers, usually without much scientific training, at one blow divorce consciousness from all forms of brain activity and hold it to be perfectly aloof and independent from changes which occur in nervous cells. To such individuals the brain is a secondary organ and its function somewhat questionable. Possibly the true ground lies somewhere between the two. It is the simplest every-day observation that states of consciousness are, so far as we know, indissolubly locked with states of brain. On the other hand, it seems in violation of all knowledge that consciousness is but a necessary physical result from the clash of nervous molecules. From the standpoint of physiology it is, however, well to remember that with this question, interesting as it may seem, we have in this field at present nothing to do.

SLEEP.

The lower centers of the brain, the mid-brain and spinal cord, and of course the sympathetic system, are in continued physiological activity. At no time during the normal existence of the individual are the physiological functions

of these centers suspended for a moment. In the higher conscious centers of the brain there is, however, a marked exception. At certain periods there supervenes what we familiarly designate as "sleep." This common phenomenon so easily experienced is nevertheless one of the most difficult of explanation, and we are at present entirely at a loss to understand what the exact nature of sleep is. We know that it concerns only the higher conscious centers. The reflex centers below are in their regular activity, unless we should modify this by the statement that during sleep the activities here are sometimes reduced, but never suspended.

Going to sleep is a sudden thing, although it is preceded by a short period in which the sensations become gradually dimmed. Waking up, too, is a somewhat sudden event. What an interesting question it would be to determine, if possible, just what occurred when sleep suddenly supervenes or when later on with similar suddenness consciousness returns. It is held by some physiologists that sleep results when no impressions reach the brain. This, of course, is at once faulty in its general application, because it is possible to go to sleep even amidst a confusion of noises and sensations. On the other hand, however, experiments have been made with animals with paralyzed sensory nerves and which were in addition to this blind and deaf on one side. When under such circumstances the only remaining sources of sensation to the brain, that is, the opposite eye and ear were closed, the animal at once dropped to sleep and awakened as soon as these avenues of impression were opened.

It has been suggested, but only as a suggestion and not a scientific fact, or even theory, that sleep may result from the slight withdrawal of the dendrons surrounding the cerebral cells. It is, of course, conceivable that these dendrons might separate to a slight extent, possibly separate so far as to make the transmission of an impulse more difficult, and that this separation, like the opening of the switch on a switch board would produce a cessation of the flow of

impulses, and so produce sleep, and that waking would consist in the moving together of these dendrons and so re-establishing the natural flow of impulses.

During sleep the entire range of conscious centers may not be affected. Sometimes certain centers or portions of certain centers seem to remain awake, and then these centers, relieved from the controlling influences of neighboring centers run riot and give rise to the production of dreams. When the centers so awake happen to be motor centers there may be produced forms of sleep in which more or less extended movements occur familiar to us under the name of somnambulism.

That sleep is not due to the lack of blood in the brain, and so be a phenomenon like fainting, is easily disproved by experiments which show that the blood supply in the brain while asleep sinks very little below the normal.

HYPNOTIC PHENOMENA.

Hypnotism is by many looked upon as an abnormal variety of somnambulism. There is, however, connected with this subject of hypnotism so much that is questionable and suspicious along with the little that is real and scientific, that it is exceedingly difficult to come to definite scientific conclusions. It is explained by some as a peculiar sleep, and looked upon by others as a mere form of embarrassment and frightened imagination.

TIME RELATIONS IN PSYCHIC PHENOMENA.

That mental processes take a certain amount of time is an every-day observation. The exact measurement of simple and definite psychical acts was first made as a result of the observation that astronomers of equal care and precision did not record the passage of a star across the hairs of their observing telescopes at the same instant. This difference in time was at first attributed to a greater or less carelessness in the observer. Repeated experiments soon showed that there was a difference in time even when both observers

had with the greatest precision noted the transit just at the moment they saw it in the telescope. These little differences of time were, therefore, due to the differences of time in the nervous systems of the observers, and so it became necessary to find out for each observer the time that he required to record the observation. This was called his *personal equation*.

In the field of physiological psychology a great deal of work has been done in determining the reaction time of the various centers. This is the interval between the perception of anything and its interpretation. A multitude of books are available everywhere, and it seems undesirable in this treatise to enter in detail into this field. Interesting, however, are the points that this reaction time may be shortened by practice, and that the reaction time may in a general way be taken as a physiological index of the individual's education of the sense in question. It is of course understood that the reaction time for complicated psychical processes will be correspondingly longer than for simpler ones, and that they need not necessarily be the same for the different sense organs. The shortest reaction time is possibly that of the eye. The further large field of interesting observations which has to do with the interpretation of sensations and their association in memory must here be referred to the field of physiological psychology in which the advances have in recent years been so great as to rank that science as one of the co-ordinate biological sciences of the day, whose field has, therefore, by the necessities of such an extension been more or less excluded from purely physiological considerations.

CHAPTER XX.

THE ORGANS OF SPECIAL SENSE.

Whenever the sensory nerves in any part of the body are properly affected, a nervous impulse arises which is then conveyed to the inner centers and may there give rise, and usually does give rise, to what we ordinarily call a sensation. Very few tissues, indeed, in the body do not have this property of sensation. These are the hairs, the nails, portions of cartilage and bone, and other forms of connective tissue, but with these obvious exceptions every tissue in the body is able to produce by its proper nerves, changes and sensations in the brain.

Sensations, however, differ at once fundamentally and fall into two groups. In one group we have the sensations which give states of feeling of our own body usually without any relation at all to the outer world. The other sensations seem to be projected beyond the body into the external world and produce in us ideas concerning the phenomena of our own environment. Thus, we have the *common* sensations of the body and the *special* sensations.

The common sensations are the general feelings of pain, of hunger and thirst, fatigue and buoyancy and possibly all the varied feelings accompanying disease. In no instance probably are these feelings ever projected into the world of things. From these we gain absolutely no notion of our environment.

In the second class belong the sensations which are produced by the organs of special sense and those general sensations of touch in so far as they give to us knowledge of external things. It is with these latter sensations that this chapter concerns itself.

There is possibly not a hard and fast line dividing special sensations from the common sensations. Thus, for

instance, a slight pressure on the finger gives an idea of the nature of the object touched. A material increase of such a pressure produces pain and no longer helps us in understanding the environment. If in the case of the eye a normal amount of light gives perceptions of sight, an excessively strong light blinds and hurts. It is probable that many forms of pain, if not all of them, are excessive stimulations of the nerves. On the other hand it is possible, especially with the sense of touch to make the stimulation of the nerves so slight as to render a distinct perception difficult. The resulting sensations in such a case we commonly designate as those of a tickling or irritating nature.

THE STRUCTURE OF AN ORGAN OF SPECIAL SENSE.

The ordinary phenomena of the external world do not as a rule affect nerves directly. In order to have such phenomena produce a nervous impulse it is necessary to provide the nerve with some form of specially adapted apparatus which shall receive the external impressions and translate or manipulate them in such a way as to give rise to a nervous impulse. In fact the difference between nerves of special sense and the ordinary nerves of the body lies in this fact. Thus we have for an optic nerve the special apparatus of the eye, the retina, for the auditory nerve the labyrinth of the ear, and for the special sense of touch peculiarly adapted corpuscles and end bulbs. The first requisite, therefore, is a specially adapted end organ. These end organs are in turn differentiated among themselves, one being adapted to one particular kind of external impressions, such as light, say, another constructed on an entirely different plan so as to catch the vibrations of sound. A third so arranged as to be easily affected by changes in pressure.

But these end organs serve merely to start the nervous impulses. They do not produce sensations of sight, hearing or touch. In fact, the nervous impulses running along the optic nerve, the auditory nerve or touch nerve are in all

probability perfectly identical, and the reason that one gives rise to sensations of light, the other to those of sound, and a third to perceptions of touch is not due to any difference in these impulses, but is due to the centers in the brain in which they end. Although such a thing is entirely impossible in reality it is possible to imagine, and justly so, that if the auditory nerve could be made to run to the visual center in the brain, sound would be interpreted as light, while if the optic nerve should end in the upper temporal lobe, colors would be interpreted as sounds.

A complete organ of special sense, then, is a special nerve center in the brain and a special apparatus at the distal end of a nerve connected with it. The phenomena of the special sensations therefore naturally fall into two kinds: the phenomena that take place in the end organs, and those that take place in the brain. Our knowledge of the processes which occur in the brain center is from a physiological standpoint so meager that for evident reasons it is here omitted altogether. Pure physiology concerns itself now mainly with those nervous changes which occur at the distal end of the nerve. We may speak of a complete sensation consisting of two events; the first, a *neurosis*—a nervous impulse of some kind produced in a special way in a special end organ and conveyed along a nerve to a special center in the brain. The second event, the *psychosis*, a conscious perception and interpretation of this nervous state as a sensation. It is difficult here to avoid confusion in the employment of the word "sensation." Frequently it is used to include both the nervous changes and the psychological results which it calls forth. At other times the word "sensation" is used to designate merely the psychological result. The reader must himself judge carefully from the context in which the word occurs what application is given to the term.

The neurosis is always the cause of the psychosis, unless one should except certain forms of mental hallucination which appear so real to the person as to be objectified.

While this relation of cause and effect is absolutely clear, it is equally clear that there is not a bit of similarity between the neurosis and the psychosis. In other words, vibrations in the internal ear, or even the nervous impulses which such vibrations produce are absolutely different in kind from those psychological sensations which we designate as sound, and there is clearly no similarity between an ethereal vibration or the stimulation of a rod or cone in the eye and what we psychologically call light. Between the two there is a chasm that cannot at present be bridged, and so all attempts at explanation are useless and out of place. To prove the assertion that there is no similarity in essence between physical light and psychological sensation of light one needs only to be reminded that the psychological sensation of light can easily be produced when no physical light is present. One needs only to be struck on the head or to have the optic nerve stimulated, electrically or otherwise, to perceive in the most emphatic and clearest way sensations interpreted as those of light. The stimulation of the auditory nerve will produce a ringing noise in a perfectly quiet medium.

To summarize, then, sensations differ in their modes or *modality*, a difference caused by the centers in the brain to which they go. Of the sensations of a separate and distinct mode, such as those of sight, there may be distinctions in *quality*, such as those of red, green or blue lights, or in *intensity*, such as a strong or faint light. There may be different qualities which we recognize as differences in touch, or different intensities which we recognize in loudness or softness. The modality of a sensation is determined by the brain center to which the nerve goes, while the quality and the intensity of the sensations of the single modality are normally determined by the end organ itself.

THE DEVELOPMENT OF THE SPECIAL SENSES.

From an anatomical, especially an embryological point of view, it is at once apparent that the special sensations

are but special modifications of the general sensations of the body. In fact, comparative anatomy could even in such a complicated structure as an eye find between the highly developed human eye and the mere pigment spot in the skin of some of the lowest animals many intervening gradations. The little pigment spot at the tip of the ray of the starfish which enables that animal to detect possibly the direction of the light merely, is but a slight advance indeed from the property of general sensations possessed by its entire nervous system. The localization of the pigment at other points than those of the tip of the ray might suffice to arouse light sensations. Such exceedingly simple forms of eye, were, however, in the development of the animal forms more and more expanded, specialized and complicated, until finally, from a somewhat common sensation, there results the highly modified retina of the eye with its accessories.

THE OBJECTIFICATION OF OUR SENSATIONS.

If it is true that special sensations are but specialized general sensations, the question naturally arises why such special sensations should be referred to the external world, whereas the general sensations are not so referred. The answer to this is at hand. It is among the simplest observations on children or adult defective people to show that these special sensations are at first not objectified. The reference of our sensations to the external world is gradual and the result of our early education and experience. In the case of touch, for instance, an object is brought in contact with the skin and a sensation results. By repeated observation it has been found that such a sensation comes from the foot, say. This the individual has found by observing possibly an object lying on his foot. Removing the same, he noted the cessation of the sensation. In this way he finally infers when he feels this same sensation that it must come from the foot. These inferences become so trustworthy finally to the individual that he does not realize at

all that they are mere mental inferences, but he seems actually to feel the sensation in his foot.

What is true of the sensation of touch might be equally applicable to all the other senses. That the reference of our sensations is a mere matter of inference may be proved by the fact that the "seeing of stars" (which results from a blow on the head) is projected through the eyes into the external world. A blow on the ulnar nerve at the elbow (the crazy-bone) results in a sensation which is referred not to the elbow where it arose, but to the fingers and hand. This mistake occurs from the fact that the brain has been accustomed to believing that all sensations carried by the ulnar nerve come from the hand. The truth of this belief has been established to the brain over and over again, and so when this impulse reaches the brain along the ulnar nerve it is without question referred to the same place, and this reference by the brain is so distinct and real that it is really hard to believe that the pain is not actually in the fingers.

That the reference of our sensations to the external world is a matter of acquirement is proved further by the possibility of educating the brain in this matter. Blind people who rely much more upon their sense of touch become remarkably proficient in localizing touches, even to the extent of being able to read raised print rapidly and accurately with their finger tips. It is also stated that persons who had been blind and whose eyesight was suddenly restored, by some kind of operation probably, did not at first see objects at a distance, but referred all of their visual sensations to the eye itself. Such persons felt a distant tree, not as an object of the external world, but as a peculiar and new sensation in the eyeball.

THE RELATION BETWEEN NEUROSIS AND PSYCHOSIS.

It was just pointed out that there is the relation of cause and effect between the nervous excitation in the end organ and the mental change in the brain. There is a relation of

cause and effect between the excitation of the retina under the influence of light and the conscious perception of light in the brain. Attempts have been made to establish a mathematical relation between the two. That there is some kind of a quantitative relation between the two is probable, for we know that a stronger stimulation of the retina by stronger light causes a stronger sensation. A harder stroke on the piano causes an increased loudness in our mental perception. Two weights resting on the hand are perceived more strongly than one. The question, however, is, what is, in mathematical terms, this definite relation. Several attempts have been made by means of extended experiments on the various sense organs to determine such a mathematical relation, the most noteworthy being that of the celebrated psychologist Fechner and known as Fechner's "Psycho-physical Law." This Psycho-physical law is, however, only a modification of the psycho-physical law of the physiologist Weber, whose work on the special senses is one of the classics on that subject. This psycho-physical law says that when the stimuli affecting the end organs vary in a geometric ratio the intensity of the subjective sensation varies in an arithmetical ratio. That is, if five units of light would produce a sensation one, then to produce a sensation twice as strong requires twenty-five lights. To increase the subjective perception of the intensity of the light to three times its original, would require one hundred and twenty-five lights. Or, to state the law in another way, the subjective sensation increases directly as the logarithm of the strength of the stimulus.

While this law is applicable in many instances it is seriously at fault in others. For instance, if one looks at a line five inches in length and then wants a sensation of a line twice as long it is of course nonsense to say that that must be twenty-five inches in order to appear twice as long. It approaches, however, the truth of things in connection with the eye and ear. Every one knows that two candles in a room do not make it twice as light as one candle.

Two voices do not sound twice as loud as one. The experiment may be easily tried in a room where there are several gas jets. After one jet has been lighted and the intensity of the illumination of the room noted, it will take a number of additional gas jets to make the room seem doubly as light.

*CONFUSION OF SENSATIONS AND INFERENCES FROM
SENSATIONS.*

Many of our so-called special sensations are really not sensations at all, but are inferences. To see the height of a tree is an inference; to see the solidity of an object is an inference; distance is wholly a matter of judgment, and the perception of size a mere comparison. It, therefore, not infrequently happens that our sensations mislead us. In justice to the sensations, however, which in a normal body probably never mislead but invariably tell the truth, it ought to be said that it is not the sensations themselves which mislead, but the inferences which we choose to draw from them. In calling attention to these inferences it is not the purpose here to carry the argument so far as to say with certain philosophers that everything is an inference and nothing a matter of knowledge; that to see a certain color plainly with the eye is not a trustworthy bit of knowledge, but a mere inference drawn from a certain state of the body. With this Cartesian philosophy physiology does not concern itself, and the sensations which arise in the body normally in every way are treated at once as trustworthy bits of knowledge from which as premises true inferences may logically be drawn.

The special sense organs are discussed in the following chapters in the order of their complexity, the simplest being taken first.

CHAPTER XXI.

TOUCH, TEMPERATURE, MUSCULAR SENSE, TASTE, SMELL.

It was long known that sensations of touch were brought about by the stimulation of sensory nerves and that the section of such nerves destroyed the sensation, but it was rather late before the special end organs of touch were discovered. The first known end organs of touch were the Pacinian corpuscles, discovered by Vater in 1741. The touch corpuscles were not discovered until 1852, when they were described by Wagner and Meissner. It was in 1846, however, when E. H. Weber published his work that physiologists arrived at the present conception of the sensation of touch and temperature.

THE ANATOMY OF THE END ORGANS OF TOUCH.

Every part of the skin is sensitive, being supplied with sensory nerves. Usually these nerve fibers end in plexuses, the final terminations of which, in the form of little fibrils, which have lost their medullary coat, end in the dermis, or may reach even in among the cells of the Malpighian layer of the epidermis and there terminate without any special end organ. In those portions of the skin, however, where the sensation of touch is specialized special end organs are found. These are of several kinds:

1.—*The Pacinian Corpuscles.* These, as just stated, were the first discovered, a fact due, no doubt, to their relatively large size, ranging from a fifteenth to a tenth of an inch in length. In the transparent omentum of the cat they are readily recognized with the unaided eye as little whitish translucent bodies. They are found in large numbers in the areolar tissue under the skin of the hand and

foot and occasionally elsewhere, as in tendons and ligaments, or (especially true of the cat) in the mesentery. A

Fig. 149.—A PACINIAN CORPUSCLE FROM THE CAT'S MESENTERY. (After Ranvier.)

n, nerve; *n'*, its continuation through the core *m*; *a*, termination of nerve in distal end; *d*, *c*, coats or capsules; *f*, a channel for the nerve.

Pacinian corpuscle is made up of a body of connective tissue which shows quite a number of concentric rings. These rings are really capsules. If one were to imagine a great number of egg shells placed one within another and the space between the contiguous egg shells filled with a little liquid the analogy to the Pacinian corpuscle would be apparent. In the center of these concentric capsules there is a soft core in which a nerve fiber ends.

2.—*The tactile cells.* The tactile cells seem nothing more than specialized cells of the lower layers of the epidermis. In regions of the skin where sensation is very acute there are found near the Malpighian layer certain cells which seem to stain more deeply, are larger, more oval and more granular than the ordinary epidermal cells. Delicate nerve fibers can be traced to them which, according to some observers, end in networks which invest these tactile cells like

the dendrons in the spinal cord but which, according to other observers, are said to pierce the cells and end directly in them.

3.—*End bulbs.* The end bulbs are found especially in

Fig. 150.—END-BULBS FROM THE HUMAN CONJUNCTIVA. (After Longworth.)
n, nerve running to end-bulbs.

the sensitive conjunctiva. The sensory fibers which reach the cornea branch and rebranch into finer fibers which form

Fig. 151.—A SINGLE END-BULB, MUCH ENLARGED. (After Longworth.)
a, entering nerve; b, capsule containing nuclei; c, c, portions of the nerve within cut across; d, e, cells making up the core.

a kind of network in the cornea. From this network branches go into the epithelium of the conjunctiva, pierce

it and end on the outer surface of the conjunctiva in little bulb-like terminations which float in the tears. The statement of Conheim that these end bulbs actually project from the cornea and float in the lachrymal fluid which continually bathes the cornea explains very satisfactorily the extreme sensitiveness of the conjunctiva. Other observers, however, deny that these end bulbs actually project above the cornea, but hold that they are imbedded in the surface epithelium of the cornea. Similar end bulbs occur in the lips and the mouth.

4.—*The touch corpuscles.* The touch corpuscles are probably the most important of all the tactile end organs, as they are found in large numbers in the skin of the hands

Fig. 152.—SECTION OF THE SKIN SHOWING TWO PAPILLÆ, ONE CONTAINING A CAPILLARY LOOP *a*, THE OTHER CONTAINING A TACTILE CORPUSCLE. (After Biesiadecki.)

d, entering nerve of three fibers; *f, f*, three fibers cut within the corpuscle. The fibrous connective tissue capsule is plainly shown.

and toes, regions which are most frequently used as organs of touch. They do, however, occur in other places such, for instance, as the forearm, lips and tongue. The extreme sensitiveness of the nipple is due to these same corpuscles. They lie in the dermis where the papillæ extend

up into the epidermis, which papillæ cause the characteristic arrangement of the fine lines so readily discernible in the palm of the hands and fingers. Some of the papillæ contain blood-vessels, but the majority of them contain touch corpuscles so that by examining these little ridges on the hand one is able to trace real rows of these tactile corpuscles imbedded just beneath. They are quite small, being only $\frac{1}{300}$ of an inch in length. In outline they are oval and consist of a capsule of connective tissue fibers wound round and round. One or more nerve fibers reach each corpuscle, and after making several turns around it enter the capsule losing at that point their medullary coats. The axis cylinder, however, penetrates the connective tissue capsule, branches several times and ends in little bulb-shaped enlargements among the meshes of the same.

Possibly the explanation of the action of all these end organs lies in the fact that any pressure on such a corpuscle would be much more likely to be transmitted by it to the contained nerve, just as fingers placed between two boards would be much more likely to notice an increase of pressure near them than if not so situated.

A very interesting form of touch corpuscles, although not found in the human body, occurs in the beak of certain birds, such as the duck. A corpuscle here consists of a capsule of connective tissue in which lie several cuboidal cells one above the other somewhat like several bricks

Fig. 153.—CORPUSCLE OF GRANDRY FROM THE DUCK'S TONGUE. (After Izquierdo.)
n, nerve.

might be stacked in a row. A nerve penetrates the capsule and sends off branches which finally end between these cells. No doubt a pressure transmitted to this corpuscle is

transmitted by the cells more effectively to the delicate nerve filaments between them. Just like a finger, to use the same illustration again, would be more susceptible if placed between bricks in such a row. This variety of touch corpuscle is designated as Grandry's corpuscle.

THE ABSOLUTE TOUCH SENSITIVENESS.

By the term of absolute sensitiveness is generally understood the minimum stimulus which is yet able to produce a sensation at the particular point in question. All parts of the skin have not the same absolute sensibility. Things which at certain portions produce no sensation at all are at other places perceived with the greatest clearness. The highest absolute sensibility seems to be on the forehead, where a minimum pressure of no more than .002 of a gram is sufficient to produce a sensation. On the temples about .05 of a gram; on the lower lip and fingers .5 of a gram, on the forearm it requires 9 grams and on the skin of the thigh as much as 17 to 20 grams.

If instead of allowing a weight to rest, as was the case in the determination of the figures just given, one should take a hair or bristle of known stiffness and that should be moved across the skin in question, the minimum pressure perceivable is much reduced. In such experiments the forehead perceives a pressure as little as .0007 of a gram; on the arm or leg about .06. These figures of course correspond with the experience of every one that the forehead, skin of the face generally, the lips and fingers are able to perceive differences in pressure which are entirely out of the question on most other portions of the body.

THE POWER OF LOCALIZATION AND THE TOUCH AREAS.

The power to localize a touch sensation is a result of experience. It may be materially improved by practice but, other things being equal, the various portions of the skin show naturally a very different localizing ability. Thus, at the tip of the tongue two points as close together as

one millimeter may still be perceived as distinct points; at the tip of the finger we perceive as two objects, points as close as two millimeters; on the wrist and arm the power to localize becomes much less and a distance of four or five millimeters apart hardly produces a double sensation. The lips require 4 mm.; the tip of the nose 6 mm.; the eyeball 10 mm.; the forehead 20 mm.; the back of the hand 28 mm., and the middle of the back and neck require as much as 60 mm. between the two points to be perceived as double.

That the absolute sensibility and the power to localize are different is evident in the case of the forehead, where absolute sensibility is possibly greater than in any other portion of the skin, but where the power of localization is only possible when the points applied are as much as 20 mm. apart. This relative power of localization has been generally described in terms of touch circles. The diameters of such circles being the least distance between two points to be perceived as double. The touch areas, therefore, on the point of the tongue are exceedingly small, only 1 mm. in diameter, while on the other extreme, the touch circles on the middle of the back are as much as 60 mm. in diameter. Two points, then, placed within such a circle are perceived as one, or in other words, to perceive two points placed on the skin as two, requires that the two points shall fall in different touch circles. It is very necessary, however, to remember that these touch areas are not definite anatomical structures, and that, for instance, it is quite impossible with a pencil to divide the skin of the back into such circles so that in every case two points coming within a circle would produce a single sensation, or placed in adjacent ones, a double sensation. For, if one point should be placed close to the edge of one such area and the other point right on the boundary line of the adjacent area so that the actual distance between the two points should be less than 60 mm., they are perceived as one. It is, therefore, not at all possible that the existence of these circles are brought about by the fact that each circle has

a single nerve going to it, and so carries but a single impulse, no matter in what part of the circle it is stimulated. That this notion is wrong is clearly proved by the fact that by practice this circle may be made much smaller, a thing which would be utterly impossible if they were anatomical units. The possible explanation is that the nerves coming from certain portions of the skin run in such a way through the centers in the cord or brain as to produce more of a radiation into the neighboring fibers or cells, and so prevent a very accurate localization. Practice in such a case would be merely the experience to eliminate these radiations and to be able to define the sensation at last to the exact nerve fibers in question.

It is given by some observers that on an average each touch area contains about twelve touch corpuscles. If this be really true, the explanation of these touch areas may consist in the possible fact that the stimulation at any point stimulates not only the touch corpuscle immediately underneath or next to it, but about a dozen of the adjoining ones, and so a rather compound sensation is carried. Where these twelve are closely huddled, as in the case of the tongue or lip, the power to localize the affected spot would be quite definite, while in the case of the scattered corpuscles at other portions of the skin, the area would be too large for exact definition.

THE SENSE OF TEMPERATURE.

Not only is the skin able to perceive tactile impressions but it is also able to take note within certain limits of the temperature of the objects affecting it. This ability to perceive the warmth of anything is, however, not an absolute one like that of a good thermometer, but is only relative. We are only able to tell whether a thing is hotter or colder than the part of the skin affected, or when the comparison is entirely between outside objects we are enabled simply to determine of these which is the warmer. This may be easily proved by immersing one hand in warm water and the other

in cold water for some time. If, now, both hands be plunged into luke-warm water it will appear warm to one hand and cold to the other.

The ability to determine differences in temperature lies within comparatively narrow limits. A reduction of a temperature much below that of the body soon produces pain. An elevation of a temperature much higher a corresponding pain or burn. The finest distinctions in temperature are made when these temperatures are about those of the body. Different regions of the body show different abilities to perceive changes in temperature. A few given in the order of their ability, beginning with the best, are, the point of the tongue, eyelids, cheeks, lips, neck. It is interesting to note that the hands and feet seem to follow no regular rule at all, but are warm or cold or insensitive under the most varying conditions. Possibly this is the result of the exposure which these parts suffer almost continually to the ever-changing temperature of their environment and so become somewhat dulled.

The sense of temperature is very exactly localized. In fact, changes in the temperature of two points may sometimes aid in their perception as two when otherwise they would have been perceived as single. The general feeling of cold and heat are not really sensations of the entire body, but are simply extended skin sensations. The body feels cold when the skin is cold, even though the interior of the body may be warm. This, for instance, is proved by the chills of many fevers, which chills are usually accompanied with an actual increase of inner temperature. On the other hand, the general feeling of warmth which the toper experiences after his draught is really not an increase of bodily heat at all, but is simply explained by the fact that under the action of alcohol the blood from the warmer visceral organs is driven through the skin. As an actual fact from the radiation of the heat going on in the skin his bodily heat is actually being more rapidly reduced.

The experiments made by Blix and Goldscheider proved the existence of distinct temperature nerves, and showed that there are on the body warm points and cold points, and that whenever a warm point is stimulated, no matter what the stimulus, a sensation of warmth results, while when a cold point is stimulated, even though it be with a warm object, a cold sensation results. These points are of course normally so arranged that the cold points are more easily affected by cold and the warm points by increase of heat. It is possible, however, to use electrical stimuli to affect both and so produce in one class cold sensations and in the other warm sensations even though the temperature in the meantime may have varied not a bit.

These temperature nerves, however, do not end in special nerve end-organs but in networks of fibers not wholly unlike the dendrons described in connection with the central nervous system. These warm and cold points are, therefore, definite anatomical structures and it is possible by carefully exploring the skin with a sharp-pointed instrument to designate these points and to make an exact map of the temperature topography.

Finally it seems probable that there is a distinct center for cold sensations and another for warm sensations. The probability of this is suggested by the fact that an arm or limb, when subjected to pressure, and so has as we say "gone to sleep," is still able to perceive warmth but is insensible to cold.

THE MUSCULAR SENSE.

When the muscles are called into action one is clearly conscious of a sensation coming apparently from these muscles and informing one of their extent and degree of contraction. It is perfectly easy for an individual with closed eyes to determine exactly the position and movements of his muscles. This can only be accomplished by the mind's taking note of the sensory impulses that come from the skin of the part moved and from the sensory

nerves distributed among the ligaments and muscles of the same part. In fact, for the proper manipulation of the muscles we are largely dependent upon the impressions which accompany the use of them. An individual with sensation lost in the arm is unable to control the movements of that arm. It not infrequently happens that when an arm goes to sleep, the power to move it returns before sensation returns, but the motions so accomplished are of the most clumsy and inaccurate kind. Experiments have shown that horses whose trigeminal nerve (the sensory nerve to the head) had been cut, found it perfectly impossible to perform even such simple muscular actions as the chewing of their food. A frog whose spinal sensory nerves are cut finds the greatest difficulty in the performance of his otherwise simplest motions. That these guiding sensations do not come entirely from the skin is shown by the fact that the skin may be entirely removed from a portion of a frog's body without interfering with the accuracy of the movement of his muscles, provided the sensory nerves going to these muscles are left intact.

In the chapter on the histology of the muscles it was pointed out that muscles themselves are not sensitive in any way, but that the sensations which seem to come from the muscles really come from sensory nerves which are distributed in among such muscles. Even the sense of fatigue of muscles has such an origin.

But not only are we able to determine the amount of motion, but it is possible actually to measure the intensity of the muscle contraction. In this way we are enabled to form judgments as to the weight of things. A weight must change from at least one-fortieth to one-tenth of its entire amount in order to perceive a difference. No doubt, however, the ability to make these distinctions varies within wide limits and is largely perfected by practice. Individuals who are in the habit of weighing things become finally so proficient as to be almost trustworthy in that matter. There are many illusions in connection with the matter of the

judgment of weights. Of objects that have the same weight those that are larger seem lighter. Again, an object seems lighter when it is elevated with both hands, instead of one. No doubt we judge of the weight of objects by noticing the amount of effort necessary to bring about the required motion. Such a sensation is really not one of the muscles, it is a measurement of the brain's own activity in the intensity of its motor impulses. This does not preclude the possibility that sensory nerves distributed in among the muscles may take part in giving us our sensations of passive movements. Not only are we able to perceive motions which we voluntarily make, but we are also able to perceive passive movements. To be suddenly moved forward, to have this motion checked or to be turned right and left, or to have the rapidity of the motion varied is at once a matter of knowledge. It seems very probable, however, that this knowledge of passive movements is in no sense connected with the muscles, or even due to the inertia of the body or its centrifugal actions, but that it is due entirely, or at least largely, to changes which are occasioned by lymph movements in the semi-circular canals of the ear, in connection with which a detailed explanation of this matter is given.

THE SENSE OF TASTE.

The sense of taste is located in certain parts of the mucous membrane of the mouth, especially on the mucous membrane covering the tongue. The under side of the tongue is not sensitive to taste. The same is true of the lips and gums and the cheek. It is asserted, however, that in small children these parts are able to give sensations of taste. The exact location of these taste areas may be easily established by taking a sapid powder and applying it point for point over these areas. A liquid would not be satisfactory for this purpose, as it would naturally spread to the neighboring areas. The sense of taste may also be anatomically located by the presence of taste bulbs. These taste bulbs, discovered by Lovén and Schwalbe in 1867, are small barrel-

shaped bodies filled with a number of spindle-like cells which at their lower extremities are connected with the

Fig. 154.—SECTION OF PAPILLÆ FROM TONGUE OF RABBIT, SHOWING POSITION OF TASTE-BUDS. (After Ranvier.)

n, nerve cut across; *v*, vein; *a*, gland; *g*, a single taste-bud.

nerves of taste and at their upper end are pointed and project to the exterior. A rather rough analogy might be made

Fig. 155.—A SINGLE TASTE-BUD MUCH ENLARGED. (After Ranvier.)

p, the open pore; *s*, taste cells; *m*, white corpuscle filled with granules; *r*, supporting cell; *e*, ordinary tongue epithelium.

by imagining an ordinary flour-barrel filled with a number of sticks, their lower ends connected with wires but the

upper ends of the sticks somewhat pointed and projecting above the body of the barrel free into the exterior. These taste bulbs are most plentiful in the circular depressions around the circumvallate papillæ and the free ends of the sensory cells project into this groove. They are also found, although not so plentifully, on the fungiform papillæ and even on the soft palate and epiglottis. Their preponderance towards the back of the tongue and mouth explains the common experience that the sense of taste is most acute in those regions. In fact, the sense of taste is rather imperfect at the tip of the tongue. Yet the tip seems best adapted for sour sensations but not so well for bitter sensations. The acuteness of the sensation in the back of the mouth possibly finds its explanation in the tendency which this gives to the animal to swallow its food.

The anatomical arrangements for the perception of taste at the tip of the tongue are quite different from the taste bulbs, the sensory nerves here ending merely in fine networks of fibrils. In the description of the cranial nerves in the preceding chapter the glossopharyngeal was pointed out as the main nerve of taste, while the taste sensations from the tip of the tongue were ascribed to the trigeminal. Some physiologists have tried to make the difference in the nerves going to these areas explain the difference in the acuteness of the sensation, but more recent work seems to show that even the fibers that go to the tip of the tongue are derived from the glossopharyngeal nerve which reach the tip of the tongue along the trunk of the trigeminal nerve.

THE NATURE OF A TASTE SENSATION.

Gustatory sensations are produced by substances, either in solution when introduced into the mouth, or dissolved by the liquids in the mouth. Gases dissolved in the liquids of the mouth may thus give rise to actual tastes. In what manner these substances act upon the nerve endings to produce the sensations of sweet, or sour, or salty, etc., is entirely unknown. We are at present entirely unable to

form the remotest conception of it. It seems probable though, that there are separate nerves for the separate tastes, inasmuch as experiments show that certain papillæ give certain tastes only, no matter how stimulated, while other papillæ give other tastes. Possibly the tips of the taste cells are chemically affected by sapid substances, certain cells readily by acids, sour substances, others by substances of the family of the sugars, producing the sweets, and so on. These impressions are then conveyed to the brain, and in the brain in a perfectly subjective way what we call the "taste" arises.

That there is a large subjective element in taste is probable from such experiments as these: Pure distilled water when tasted immediately after tasting salty water tastes distinctly sweet. Still more remarkable is the fact that a dilute solution of sugar becomes distinctly sweeter to the taste when a little bit of salt has been added to it. The intensity of the sensation depends not only on the strength of the solution to be tasted, but also on the amount of taste area in the mouth in contact with that solution. For this reason a person tasting a thing tries to spread it out as much as possible over his sensory area. Rubbing the substance, pressing it against tongue or palate sharpens the taste, no doubt because it facilitates the introduction of the sapid substance into the depressions around the circumvallate papillæ in which the taste buds lie.

Taste sensations are frequently confused with odors. Possibly in the majority of instances when a person imagines he is tasting something, the sensation is really due to his olfactory sense. With the destruction of the sensibility of the nose goes the possibility to taste such apparently sapid substances as coffee, tea, or the ordinary flavors of fruits. In fact, the number of tastes are limited and are usually classed in four kinds, namely, bitter, sour, sweet and salty. In each class there are, of course, large numbers of slightly varying qualities.

THE SENSE OF SMELL.

The sense of smell is located in the olfactory region, which includes the mucous membrane covering the folds of the ethmoid bone, and the turbinated bones. The mucous membrane in these parts is not provided with cilia, as it is in the regular respiratory tract behind. The difficulty of

establishing definite end organs concerned in the sense of smell is even greater than in those of taste, and the histology of the mucous membrane reveals but slightly differentiated structures for this purpose. There are, however, in the epithelium covering this mucous membrane certain more slender cells placed in between the ordinary epithelial cells. These more slender or sensory cells are connected with fibers from the olfactory nerve beneath, are pointed at the upper end, which point projects very slightly above the mucous membrane into the nasal cavity. The statement of some observers that in the human nose these sensory cells have little hairs or cilia at their end is probably not true. It is true, however, in the case of birds and amphibians. These possess on the ends of these cells rather long immovable hairs. The absence of such hairs in man may account for his bluntness of this sense

Fig. 156.—OLFACTORY CELLS.
(After M. Schultze.)

1, from the frog; 2, human;
a, ordinary epithelial cells;
b, olfactory cells; c, peripheral process prolonged in 1 into fine hairs; d, their central ends connected with the nerve.

when compared with the intense acuteness of that of some of the lower animals. The tips of these cells projecting into the nasal cavity are the points where the stimuli that produce sensations of odor affect the nerves. It is at once apparent how much more efficient such a stimulus would be when acting upon a number of sensitive protoplasmic hairs projecting freely above the surface than when obliged to act

on a relatively blunt end only slightly raised above the general epithelial level.

As in the case of taste, so here there is absolutely no knowledge at present as to the exact manner in which the sensations of smell are produced. Possibly here, too, the subjective element plays a very important part, for it not infrequently happens that a person who has experienced an exceedingly unpleasant odor (such, for instance, as those associated with a corpse) will have this odor recur after that from time to time with the clearest exactness, although every possibility of the offending gases actually having affected the nose was precluded. Smell sensations are occasioned by the introduction of gaseous substances only, but the intensity of the sensation depends not only upon the strength of the gas, but also upon the circumstance that this gas must stream through the nose. A gas allowed to rest in the nose soon ceases to affect the membrane. For this reason the air is always sniffed when the odor of anything is to be detected.

One of the most remarkable things about the sense of smell is that it may be aroused by almost inconceivably small quantities of odorous matter. Musk, for instance, may fill large spaces with its odor and do so for relatively long times, and yet not lose measurably in weight.

A further interesting fact is the inability we have of forming anything like a scale of odors, or even our inability to divide them into related groups. In fact, we are unable to designate them with definite names, but apply to them the names of the objects in which they occur. We are also further entirely unable to analyze odors into their components, a thing which can be easily done in the matter of colors with the eye, or still more easily with sounds in the ear. Even when one nostril is filled with an odor of one kind and the other nostril with a different odor, the two sensations do not blend at all, but we perceive now the one, now the other, depending upon the relative strength or sensitiveness of the two nostrils.

CHAPTER XXII.

THE EAR.

The ear is an apparatus constructed according to such physical and physiological laws as will enable it to take cognizance of sound vibrations. The adaptation of this organ to physical sound vibrations is one of remarkable perfection, exceeding, possibly, any other instrument which has to do with the manipulation of sound waves. Evidently, therefore, it is necessary in order to understand the anatomy and physiology of this sense organ to become somewhat acquainted with the physical properties of sound waves.

THE NATURE OF SOUND.

Sound, that is, sound viewed from its physical standpoint, is a vibratory motion. The body moving may be either gaseous, liquid or solid. The vibration is, however, a molar vibration; the mass of the medium in question must vibrate. In this sound differs fundamentally from heat and light, which are also forms of motion, but these latter are produced by the molecular motion of the body giving out the heat or light. This distinction may be easily made clear by imagining a bell struck first with a hammer. The blow sets in vibration the entire mass of the bell. This vibration may be felt with the finger, and a small object suspended near the bell is violently thrown away from it as soon as it touches it. One is able almost to see the oscillation of the whole metal backwards and forwards. If the bell be grasped and held firmly it soon ceases to vibrate and the sound is gone. If, on the other hand, such a bell should be placed over a fire it would gradually become warmer and warmer, and if the heating process should continue, might even be raised to a red heat, and so produce light. In this instance it is not the whole mass of the bell

moving together, but it is a molecular motion throughout its substance. Touched with an object, the heat vibrations do not cease, and a small piece of metal placed in contact with it is not violently thrown off. In other words, sound is a vibratory motion of the mass of an object, heat and light of its component molecules.

THE PRODUCTION OF SOUND.

From the vibratory nature of sound it follows that sounds may be produced in an endless variety of ways, the requirement in each case being simply that some kind of a body be set in rapid motion and that this motion be transmitted to a suitable medium. A familiar object for the production of sound is the tuning-fork, the vibrations of which are very apparent when sounding; in the case of the organ the metal tongue is set in vibration by the air thrown against it; in the piano it is the strings made to vibrate by the stroke of the key against them, while in wind-instruments the air itself within is set into definite oscillations.

THE RANGE OF THE NUMBER OF VIBRATIONS IN THE PRODUCTION OF SOUND.

It is not every vibration that produces a sound. It is not until the vibrations reach a certain frequency that they become perceptible to the ear. The minimum number of vibrations to be so perceptible varies a little for different ears, but is in the neighborhood of sixteen per second. A string vibrating fewer times than sixteen per second produces no perceptible sound, although its vibrations may be distinctly visible to the eye. Vibrations above this lower limit are audible. There is, however, an upper limit beyond which the ear is not able to go. This upper limit also varies for different ears, but seems to be in the neighborhood of 60,000 vibrations to the second. These limits between which the human ear is able to appreciate sounds comprise a range of about thirteen octaves. A high-grade piano has usually no more than seven octaves, or seven and one-third. The

superiority of the ear as an organ for catching sound several octaves higher and lower than the piano is at once apparent.

The compass of the human voice is about three octaves only. Deep F of the bass singer has about 87 vibrations, and the upper G of the soprano about 775 vibrations per second. Voices exceed these limits only in very exceptional cases. It will be pointed out later that the limits of the ear are not limits imposed by the vibrations themselves, but that these limits are produced in consequence of the anatomy of the ear, the basilar membrane having an extent of about thirteen octaves only. It is, of course, entirely possible, in fact probable, that an anatomical extension of this structure in the ear would have materially increased the range of the musical scale which might be perceived.

*THE TRANSMISSION OF SOUND IN THE AIR AND ITS VELOCITY
IN THE SAME.*

The usual medium for the transmission of sound is, of course, the air. Sound is unable to pass through a vacuum. A sounding body placed under a bell jar of an air-pump and the air then exhausted, cannot be heard, no matter how violently it may be in motion. The admission of air into the receiver, and so the formation of a medium around it for the transmission of sound at once makes the sound loud and clear. Sound waves in air differ, however, in form from those produced by the tuning-fork or a string. The sound waves in air go in all directions from the sounding point in the form of concentric spheres, somewhat like the circles that radiate from the surface of a body of water from the point where a pebble has been thrown into it. In the case of the air, these waves do not extend in the form of circles but in the form of spheres. In a sound wave the particles of air are set in motion in such a way that they produce spheres of condensed air and rarefied air, and it is these waves of condensation and rarefaction that are transmitted, and, of course, not the particles of air themselves.

These waves go with a velocity which can be readily determined. That sound waves are much slower than rays of light is proved by the experience of every one who has seen the steam of the whistle of an approaching train several moments before he hears the sound. Or he may have noticed the discharge of a gun or the flash of the lightning before he hears the sounds which these have produced. The velocity of sound vibrations through the air depends upon the density of the air, and as the density of the air depends upon the temperature it is usually said that the velocity of a sound depends upon the temperature of the medium. At the temperature of freezing, the velocity of sound is about 1,092 feet per second. For each additional degree of centigrade the velocity is increased about two feet per second, so that at ordinary mild temperatures the velocity of sound in air is not far from 1,120 feet per second.

REFLECTION AND REFRACTION OF SOUND.

Sound being a vibratory motion it is subject to the same laws of reflection and refraction as light. A sound wave, for instance, striking a high wall or precipice is reflected back and gives rise to what is familiarly known as the echo. An echo in sound is, therefore, like the reflected image in a mirror in the case of light.

But not only may sound be reflected like an echo, it may be refracted like light through lenses. To do this it is simply necessary to pass the sound wave through a denser medium to converge it, or a rarer medium to diverge it. A large rubber bag shaped like a double convex lens and filled with carbon dioxide, which is denser than air, serves as a condensing lens, somewhat like glass does for light. Very seldom, however, are sound lenses brought into use.

A familiar result, depending upon the refraction of sound, is produced in the carrying of sound by the winds. It is apparent that a sound is much plainer when the wind blows from that direction. The familiar explanation is, of course,

that the sound, like autumn leaves, has been blown along by the wind. This is, however, a mere figure of speech. The real explanation consists in the fact that the air being blown over the ground and meeting with resistance there is somewhat condensed, and being therefore denser on the ground than it is further up where there is no resistance to be overcome, the sound waves are deflected towards the ground, by this denser air near it acting like an ordinary lens. In this way much of the sound which would otherwise have radiated upwards into the sky is refracted to the ground and so the perception of the sound made more distinct. The analogy in the case of light occurs, for instance, at the rising or setting of the sun when by means of the refraction of the atmosphere the sun becomes visible in the morning really before it comes above the horizon, and remains visible in the evening some time after it has really set, due to the fact that the rays of light which would have gone off into space are by the atmosphere, like a lens, bent down to the ground.

THE PHYSICAL PROPERTIES OF SOUND.

1.—*The Intensity or Loudness.* Sounds are easily distinguished as louder or softer, and this distinction in loudness is described as the intensity of the sound. This intensity is produced by the intensity of the vibration, not by the frequency or number of vibrations. This must remain the same. The intensity is in the added distance through which a single vibration moves. Thus, in the case of a piano string if it be struck very lightly, it vibrates up and down through a very small distance, if it be struck harder the number of its vibrations is not increased, but the string at every vibration passes through a greater amplitude. The explanation of intensity may be easily shown to the eye by the pendulum. One can easily satisfy himself that a pendulum of a definite length makes no more vibrations in a given time when it swings out far to the right and left at each beat, than when it moves but little out of its vertical posi-

tion. No matter if the pendulum of a large clock should move through an arc of only a degree, or if it should move through an arc of ninety degrees would the number be changed, but it is of course evident that when moving through ninety degrees the stroke is more intense than when moving through one.

If a tuning-fork by means of a point at its vibrating ends could be allowed to trace its vibrations on a revolving drum the intensity of the sound would be pictured to the eye by the height of its waves. Intensity, therefore, is usually explained by saying that it is that property of a sound which depends upon the amplitude of the vibration. Loudness in sound is brightness in the case of light.

2.—*Pitch*. We readily distinguish sounds as higher or lower, and we speak of bass, alto, tenor and soprano parts when we have these distinctions in mind in the case of singing. This highness or lowness, or, in other words, the pitch of a sound, depends upon the number of vibrations per given time, of which the sound is composed. For instance, sixteen, or more generally thirty-two vibrations per second is the lowest note audible. Middle C on a piano (French pitch) is 256 vibrations per second, while the upper C on the piano has over 2,000 vibrations to the second. Pitch is expressed in another way, by stating that it is that property which depends upon the length (not height or amplitude) of the vibrations. This is but saying the same thing in another form. In a note which has 2,000 vibrations per second the individual waves must be much shorter than in a note that has but 32. Just as in a chain having 100 links to the foot, the individual links must be much shorter than a chain having but three links to the foot. Evidently the *number* of links and the length of the individual links express the same thing.

Other things being equal, the pitch which a sounding body will produce will in the case of tuning-forks or vibrating tongues depend upon the length of the fork or tongue,

the pitch being higher the shorter the tongue. In the case of stringed instruments the pitch depends upon the tightness with which the string is stretched, as well as upon the length of the string. In the tuning of a violin, for instance, the pitch of the string is first determined by the tightness, and after that, the pitch is varied by shortening the length of the string in definite proportions by placing the finger upon the same.

3.—*The Quality of Sounds.* If in the same room a note should be sounded by each of a half dozen instruments and the intensity and pitch of this note be made as nearly the same as possible, the ear could nevertheless distinguish without the least difficulty between the sounds produced by the violin, the piano, the horn, the organ, or the human voice. This property of a sound by means of which, even when pitch and intensity are the same, we are able to make these very definite distinctions is called the quality of a sound. There are, therefore, as many different qualities as there are kinds of sounds. Even in the case of human beings nearly every voice has its own quality and we are able to recognize an individual very readily by his voice. The question now arises what the physical basis for the distinctions is.

This is not so easily made clear without having at one's disposal a more detailed knowledge of harmonics than can be assumed in this discussion. A few hints or suggestions, however, as to its explanation may be helpful. If we picture to ourselves sound waves in the form of water waves, it is evident that the height of a wave represents the loudness of the sound, and the length of the wave; that is, the distance from the crest of one wave to the crest of the next one, represents the pitch. Now, in this analogy the *form* of the wave determines the quality of it. Every one who has been at the lakeside or at the seashore, or, still better, far out on the ocean, must have been struck with the variety of the forms of waves from the gentle, undulating swell with

its unbroken glassy surface like a bulged mirror, to the ploughed, choppy waves of the English Channel or Irish Sea. He has noticed how the surface of a big wave is sometimes covered with smaller waves, and these individual smaller waves, in turn, roughened with ridges upon them. It is not difficult to see how the form of a wave on Lake Michigan might differ materially from the form of a wave on another body of water, even though the height of the waves and the lengths of them be the same. This difference in form produces the quality of the wave, and if we had special senses to take cognizance of such water waves, probably one would have no difficulty in distinguishing between a Lake Michigan wave and a wave from the Gulf of Mexico, or another from the middle of the Atlantic.

Leaving this analogy and defining quality in the terms of sound waves it is this: The quality of the sound depends upon the number of secondary waves or secondary sounds which are super-imposed upon the first fundamental wave or sound. This was conclusively shown by the experiments of Helmholtz, who, by means of properly combined tuning-forks was actually able to produce the qualities of different instruments. To use the analogy of light, quality would be produced by taking a fundamental color and then tinting or shading that color within narrow limits by the addition of secondary colors. If, therefore, the quality of a sound is due to its compounding, the question naturally arises, what would be the quality of a sound perfectly pure without the admixture of secondary waves. Such sounds are produced with relative purity by tuning-forks, and any one who has heard a high-grade tuning-fork must have been struck by its mellow, pure, unmixed quality. If, now, to such a fundamental pure sound other tuning-forks in varying strength and of proper pitch be added it would be possible to reproduce the piano note, or tone of the violin, and we may add even the quality of the human voice.

HARMONY.

A succession of notes varying in pitch and possibly other properties is spoken of as a melody. Melodies need conform to no especial physical rule, but are almost wholly determined by the likes or dislikes of the composer. A pleasing melody to one is not necessarily so to the next. A much more definite arrangement of notes occurs in harmony. By harmony is understood the consonance of two or more sounds. Any two sounds when sounded together are by no means necessarily harmonious. In fact, if the sounds were selected at random the chances would be very much in favor of their proving discordant to the ear. Harmony is dependent upon the consonance of definite specific sounds, and is, at least with the majority of civilized people, the same for all persons. Every normal ear hears as a pleasant sound the consonance of a note and its octave. Every player on the piano knows that C and G produce a pleasant effect when sounded together; that the same is true of C and E, or C and F, confining ourselves in this illustration to the key of C. C and B produce a discord, C and G^b are displeasing. We have now to determine what physical property it is that determines the consonance or dissonance of notes. In doing so it is necessary to bear in mind that a consonance or dissonance is first determined by the ear, apart from any physical considerations of the sounds in question. A person who knows not the first elements of the nature of sound may be perfectly able and is perfectly able to feel the pleasurable effects of certain combinations of sounds, and the displeasing effects of others. The proper chords on a piano or in an orchestra please the ears of the attuned or untuned alike, within large limits. The determination of the physical nature of harmony, therefore, consists merely in determining the relations of notes which have been previously selected by the ear as harmonious.

When, now, notes which are harmonious are examined experimentally, it is soon established that *the physical basis of harmony is the simple mathematical ratio of the number*

of vibrations of the component sounds, and the notes are more harmonious as the mathematical ratio of their numbers of vibrations becomes simpler and simpler. Evidently the simplest mathematical ratio is 1 to 1, but this, of course, is unison. The next simplest mathematical ratio is 1 to 2. This is the ratio of a note and its *octave*; that is to say, the octave above a note has always just twice as many vibrations as the note itself. If middle C, therefore, has 256, the C just above in order to be a harmonious octave must have 512. The next simplest ratio is 2 to 3. This ratio is found to exist between a note and the *perfect fifth* of that note. Using the key of C in all of this, it is the combination of C and G. In other words, for every two vibrations in C, G has three, or, if C has 256 G has 384 per second. The next simplest ratio possible is 3 to 4, and this proportion in their vibrations exists between C and F. The ratio of 3 to 4 is thus found in the *perfect fourth*. The ratio of 4 to 5 is the ratio of the interval between C and E, or the *major third*. The ratio of 5 to 6, 6 to 7, 7 to 8, 8 to 9, and so on, are becoming too complicated to appear harmonious to the ear, and we feel these ratios as dissonances. But there are other simple ratios; 3 to 5 is a simple ratio, and this is a ratio which exists between C and A, the *major sixth*. The ratio of 1 to 3 exists between C and G in the next octave, while the ratio of 1 to 4 exists between C and the upper C of the next octave.

All these ratios are simple ratios, and it is this simplicity of ratio, which is simply the rhythm of their vibrations expressed mathematically, that produces the effect of harmony upon the ear, or rather, upon the mind.

Complex ratios become more and more dissonant, while very complex ratios finally lose all harmonious qualities and tend to become mere noise. If the question be asked why notes having a simple ratio to each other appear pleasant, or harmonious, the answer would have to be referred outside of the domain of physiology. It would probably be that the mind naturally and for inexplicable reasons likes

definite rhythms, and when these rhythms are easily perceived; that is, are mathematically simple, we become conscious of this pleasure.

Something of this rhythm appeals to the eye. Soldiers that march in unison present a pleasing appearance. A company of soldiers composed of a column of adults and a column of boys marching in such a way that the boys would take two steps while the adult soldiers took one step would be very pleasing to the eye. The interval between the two columns of soldiers would really be an octave. We can imagine the pleasing effect of two columns marching with such regularity that for every two steps of one column the other should take three, so that at every third step of the second column all of the soldiers would step together. This would be the interval of 2 to 3, or the perfect fifth. If, finally, all mathematical ratio should be lost, or at least become very complex, we would no longer be able to perceive any rhythm in the march, and the column now would present nothing but an ordinary crowd rushing in confusion down the street. This, in terms of sound, is mere noise.

In the building of a musical instrument, therefore, such, for instance, as the piano, which has only a certain number of keys, the point is to pick out those notes which bear these simple ratios and omit those of complex ratios. In this way there is produced what is commonly called the scale, consisting of eight sounds. The vibrations determining these notes are in the proportion of the numbers as here given:

$$\begin{array}{cccccccc} C & D & E & F & G & A & B & C \\ 1, & \frac{9}{8}, & \frac{5}{4}, & \frac{4}{3}, & \frac{3}{2}, & \frac{5}{3}, & \frac{15}{8}, & 2. \end{array}$$

Cleared of fractions these proportions may be expressed by the numbers,

$$\begin{array}{cccccccc} C & D & E & F & G & A & B & C \\ 24, & 27, & 30, & 32, & 36, & 40, & 45, & 48. \end{array}$$

Thus for every 24 vibrations of C, D will have 27, A 40, and the upper C 48, etc.

Evidently in harmonics we are not concerned with the absolute number of vibrations but only with the relative. We may select as the number of vibrations of our fundamental note any desired number, but once having selected this number arbitrarily, the others must bear these definite ratios to it. Thus, the French standard for middle C is about 256; the C of the Italian opera has about 273, while a Musical Congress in 1834 at Stuttgart recommended 264 as a standard for middle C.

Expressed then in physical terms, a harmonious chord on the piano is a combination of those notes which bear simple mathematical ratios. Taking the key of C, such a chord would be composed of C-E-G and C, or C-F-A and C. These are the ordinary combinations. Music begins to be less and less harmonious as the ratios become more complex, and when the ratios can no longer be perceived at all we speak of sounds as mere noise.

SYMPATHETIC VIBRATIONS.

In order to understand the manner in which sounds in the air finally succeed in stimulating the internal ear, it is necessary to understand those phenomena of vibrating bodies designated as sympathetic vibrations. It is a very general experience, when singing a clear note near some musical instrument, that the musical instrument will catch up that tone and give it out itself. Sometimes it is necessary to remove instruments from the room to prevent this interference. Two tuning-forks tuned alike and placed near each other mutually affect each other. If one tuning-fork be sounded the vibrations from that tuning-fork will put the second tuning-fork in vibration, even though it was perfectly silent to begin with, and the second tuning-fork may go on sounding after the first one has been mechanically stopped. In a music store where numbers of instruments are found close together the strong sounding of a chord on one piano will usually set similar chords vibrating in the other pianos. These phenomena are produced by

having the strings of the other instruments set in sympathetic vibration by the sound waves emanating from the first.

It must be noted, however, that one note will produce a sympathetic vibration of another only when the two notes so produced are of the same pitch, or bear at least harmonic ratios to each other. To sing middle C into a piano will set in vibration the string of middle C, not that of D or B. To understand the nature of sympathetic vibrations thoroughly means to understand the manner in which the vibrations of the air are finally transmitted to certain chords in the ear.

The ear has a piano-board in it and sounds entering it will set in sympathetic vibration those chords which are attuned to them.

The physical explanation of these sympathetic vibrations is simple. One can easily see how a very slight wind which would come in regular puffs might set a very heavy object swinging after a while if these puffs should occur at such regularities that they would always strike the swinging object just at the proper time. When the waves of air are synchronous with the vibrations of the body a slight wave may soon put in motion a relatively large body. If we imagine an individual sitting in a swing and pushed with but one finger, but the push administered just at the moment when the person is swinging away from the finger, so as to get the full benefit of the push, the swing may be soon set in motion by these slight finger tips.

So with the vibrations entering the ear and striking a certain string whose vibrations are exactly attuned to it, they finally set it going and so give rise to the production of a second sound which is the counterpart of the first.

Having in this preliminary way called attention to some of the elementary but fundamental properties of sound, it is possible to more intelligently understand the somewhat complicated anatomy of the auditory apparatus itself.

THE ANATOMY OF THE EAR.

The sense of hearing has, of course, from time immemorial been attributed to the ear, and some explanations as to the manner in which hearing occurred were advanced with fair accuracy by very early writers. It was, however, reserved for the last decade to very materially advance our knowledge. It was impossible to understand the perception of musical sounds until Corti, in 1846, worked out carefully the anatomy of the cochlea, and especially the membranous cochlea. The rods of Corti bear this observer's name. The finer anatomy of the vestibule and the ampullæ was understood when the work of Max Schultze on these structures was published in 1850. In 1842 the physiologist Florens, and in 1869 Goltz advanced the idea that the semi-circular canals were not directly concerned with hearing, but were organs of equilibrium. It was, however, reserved for Helmholtz to study with the greatest care the individual parts of the ear, and to him we are indebted largely for the present conception we have of the function of that organ, as well as for the theory of harmony in terms of which the various phenomena of musical sounds are explained.

THE EXTERNAL EAR.

The external ear is composed of the outer shell of the ear called the concha, and the opening leading to the tympanic membrane designated as the auditory meatus.

1.—*Concha.* The concha consists mainly of elastic cartilage and serves to collect the sound like a funnel and direct it into the auditory meatus. As such a collector of sound it is, however, very deficient in human beings. The external ear may be entirely removed without apparently interfering with the acuteness of hearing. In the lower animals its efficiency as a collector is unquestioned. In these animals it is relatively much greater, is more definitely funnel-shaped, and is movable in such a way that it may be placed in the most advantageous position in gathering the sound. In the human ear it has lost most of these proper-

ties and so may be looked upon, physiologically at least, as an inherited remnant of a once more serviceable structure.

Fig. 156.—A SEMI-DIAGRAMMATIC SECTION THROUGH THE RIGHT EAR.

A, auditory nerve; B, semicircular canal; G, meatus; M, concha; T, tympanic membrane; P, middle ear; R, Eustachian tube; S, cochlea; Vt, scala vestibuli; Pt, scala tympani; r, round foramen; o, oval foramen. (The membranous cochlea is not shown.)

2.—*Meatus*. Through the auditory meatus the sound waves are led to the tympanic membrane. The meatus is lined with skin, in which are imbedded numerous wax glands, the secretion of which serves to keep the wall of the passage, as well as the tympanic membrane at its end, in a pliable condition. The presence of relatively large hairs in it serves mechanical purposes only, in preventing access to foreign bodies. It was held by some physiologists that the external auditory meatus serves as a resonance cavity for the sounds, but owing to its small size this physical effect is very trifling, and what resonance there is in connection with the ear belongs probably entirely to the middle ear.

As the efficiency of the eye may be materially increased by the addition of optical instruments, so it is possible to magnify the perceptive capacity of the auditory meatus by special instruments, such as ear-trumpets and the professional stethoscope.

THE MIDDLE EAR.

The middle ear or tympanum consists of a small cavity lying between the external auditory meatus and the inner ear. Its size in man is from three-quarters of an inch in its widest dimension to about a half inch in the direction at right angles to this. It is, therefore, although a small opening almost as large as the entire internal ear, or in space equal to the external auditory meatus.

1.—*Eustachian Tube.* This cavity is filled with air which is able to reach it through the Eustachian tube. This tube runs from the middle ear and opens into the back part of the mouth. By means of this tube the pressure of air in the tympanum is kept the same as that of the surrounding atmosphere, and so barometric changes in it do not exert their effect upon the tympanic membrane as would otherwise happen. Through this Eustachian tube the mucous membrane of the middle ear is a continuation of the mucous membrane of the mouth, a condition which unfortunately makes possible the extension of an inflammation into the middle ear from the mouth, such as occurs in some forms of catarrh. An inflammation of the middle ear and Eustachian tube soon causes the closing of the Eustachian tube by its swelling, and thus the only exit for the matter which may be produced is by rupturing the tympanic membrane and escaping through the auditory meatus. Such a result is usually designated as a gathering in the head. The Eustachian tube is usually closed, the two walls of it are pressed together and separate regularly only during the process of swallowing. The explanation of the regularly closed condition is found in the fact that such a closing prevents the sound from entering the middle ear by that avenue, and so to some extent interfering with the sound reaching it regularly, and, secondly, that it prevents the sounds produced in the mouth (the voice), from reaching the ear with the force that they would do if this canal were open.

2.—*Tympanic Membrane.* The tympanum or middle ear is separated from the auditory meatus by a delicate membrane called the tympanic membrane. This membrane consists of three coats: a connective tissue membrane covered on the outside with the skin of the auditory meatus and on the inside with the mucous membrane of the middle ear. This tympanic membrane is set somewhat diagonally across the end of the meatus and its surface toward the meatus is concave. This concavity is produced by the circumstance that the malleus is by its handle firmly attached at the middle of this membrane and tends to pull it inward. Its concavity towards the exterior possibly serves to gather up the sound waves and center them on the spot where the malleus is attached.

The tympanic membrane is affected by sound waves in such a way that it is set into vibrations corresponding precisely with the vibrations of the entering sounds. This function of the membrane is well shown in the telephone. The box into which one speaks has stretched across it at its base, just in front of the electric magnet a delicate metal diaphragm. Against this diaphragm or tympanic membrane, so to speak, the voice is thrown and sets it into vibrations which correspond exactly to the vibrations of the air affecting it. Such a telephone membrane is able to catch the vibrations of a high note as well as a low note. It is, in fact, able to transmit to the magnet back of it all the vibrations which strike it.

Such is almost exactly the case with the tympanic membrane. This membrane has, however, one or two arrangements by means of which it can adjust itself to sounds. Attached to the malleus there is a muscle called the tensor tympani, by the contraction of which the tympanic membrane is pulled further inward, thereby made more concave and of course becoming more stretched. This probably helps in the perception of high sounds. It is further possible that this tensor tympani is brought into play when we listen attentively for some time to a definite sound. One

can readily understand that a tightly stretched membrane is more serviceable for collecting sounds, especially high sounds, than a less taut one.

There seems little reason, though, for attributing very much to this muscle. The membrane in the telephone is able to catch the widest range of tones without its stretch being varied, and so there seems no difficulty in attributing the same physical possibilities to its analogue in the ear.

3.—*The Bones of the Ear.* The vibrations of this tympanic membrane must now be carried across the middle ear to the internal ear where the real sensory apparatus of the ear lies. This is done by a series of three small bones, known as the hammer, anvil and stirrup; or, using their Latin equivalents, the *malleus*, the *incus* and the *stapes*. These three bones really represent four bones; as the incus consists really of two separate bones, the incus proper and the small, round *orbicular* bone which finally grows to it and which serves to attach the incus to the stapes. These three bones are arranged in such a way as to form a system of levers, by means of which the vibrations of the tympanic membrane are carried across the middle ear and with mathematical precision transmitted to the inner ear through the oval foramen.

A somewhat ingenious arrangement is found in the articulation of the malleus and the incus. These at their point of contact fit into each other in a kind of dovetail fashion, owing to the presence of peculiar interlocking teeth, so arranged, however, that the least motion of the malleus inwards is at once by means of these cog-like teeth transmitted to the incus and so to the internal ear. A violent motion, however, of the malleus outward does not draw the incus with it. In this way there is prevented the possibility of having the stirrup pulled out of the oval foramen in case the tympanic membrane should be suddenly and forcibly pressed outward. The value of this arrangement is evident when we remember how easily one might

in certain forms of blowing, force the air through the Eustachian tube into the middle ear, and thereby push out the

Fig. 157.—THE BONES OF THE MIDDLE EAR, WITH ARROWS INDICATING THE DIRECTION OF MOVEMENT OF EACH BONE IN THIS SERIES OF LEVERS. *a*, *am*, FULCRUM POINTS.

tympanic membrane, the result of which would be to pull its chain of bones with it, even at the risk of pulling the stapes entirely out of its moorings. But this is prevented by the arrangement of the teeth between the incus and malleus in the manner just stated, so that while a motion inward is at once communicated to the incus, a motion outward affects the malleus alone.

The exact manner in which these bones work may be easily understood from the accompanying diagram, in which the direction of motion of the various parts is indicated by arrows. It will be noticed that the malleus moves like a lever of the first class, its fulcrum being near its middle at the point where it is fastened by means of the ligaments to the wall of the middle ear.

4.—*The Cavity of the Middle Ear.* The function of the middle ear is its ability to act as a resonance cavity. But for this fact the tympanic membrane might have been stretched across the oval foramen at once. Sounds are materially strengthened when brought near resonators. The note of a violin is to a very large extent made possible by the resonance of the violin frame beneath the string. It is the piano-board almost as much as the string that gives the tone, while in the case of a horn, tones would be impossible without the resonance cavities in the horn. A tuning-fork

sounded by itself sounds but feebly, but placed on a resonance box of the proper kind it is increased many-fold in strength. So, too, in the middle ear the air serves such resonance purposes. Even the bone surrounding the middle ear is very porous, indeed, and it is not impossible that this porosity may help to increase still further this resonance function.

It will be noticed that both external and middle ears were purely physical arrangements to transmit the sound in a definite way to the internal ear where the real act of perception occurs.

THE INTERNAL EAR.

The real sensory internal ear, that part to which the auditory nerve is distributed, is a series of membranous canals and sacs which lie in corresponding openings in the petrous portion of the temporal bone. We have therefore to do first with the bony internal ear, by which is meant nothing more than that system of spaces in the bone in which the membranous or sensory ear is located. The membranous ear does not, however, occupy all of the space of the bony ear, but floats in the perilymph, a liquid which fills this space.

The bony ear shows three well-marked divisions which appear also in the membranous ear. First, the vestibule; second, the semi-circular canals; third, the cochlea. These three portions are continuous so that the perilymph in the vestibule might, if it could be set in motion, pass through any one of the semicircular canals or flow up the windings of the cochlea.

1.—*Vestibule.* The vestibule has a large opening communicating with the middle ear. This is the *foramen ovale* into which the end of the stapes fits. It is evident, therefore, that the vibrations communicated to the internal ear by the stapes reach the perilymph of the vestibule.

Connected with the vestibule towards the back and slightly above are three semicircular canals arranged like

the three diameters of a cube. One is vertical, the other vertical at right angles to this, and the third horizontal.

Fig. 158.—RIGHT BONY LABYRINTH SEEN FROM THE OUTER SIDE. (After Sömmerring.)

The smaller figure below gives the actual size. 1, vestibule; 2, foramen ovale; 3, 4, 5, semicircular canals; 6, 7, 8, cochlea; 9, foramen rotundum. (The immediate walls of the bony labyrinth are denser than the outer portions, and the view above results when the softer bone has been, piece by piece, picked away.)

2.—*Cochlea*. At the forward end of the vestibule this space communicates with the cochlea. This structure, named from its resemblance to a snail shell, has two and one-half windings. It is a tube coiled up like a snail shell, possibly merely to save space. Drawn out it would be a straight tube not unlike a small dinner-horn.

The cavity of this coiled tube is, however, divided into an upper and a lower chamber, the upper one being called the *scala vestibuli*, the lower the *scala tympani*. The division is formed partly by a partition of bone called the *lamina spiralis* and partly by a thin membrane called the *basilar membrane*. These two chambers are so arranged that the *scala vestibuli* is a direct continuation of the cavity of the vestibule.

The *scala vestibuli* runs to the top of the cochlea, and at the top, on account of the absence of the partition at this point, it communicates with the *scala tympani*, while the *scala tympani* at its lower end communicates with the middle ear through the *round foramen*. Both these *scalae* are filled with perilymph.

Let us imagine the possibility of an object moving around in the perilymph. Such an object starting in the vestibule might move backwards and pass through any one of the three semicircular canals, going up one and down the other. Afterwards it might move back through the perilymph of the vestibule and go into the scala vestibuli. This it might ascend, by taking the two and one-half turns of the cochlea, to the very summit. The continuity of the partition all along the cochlea formed by the lamina spiralis and the basilar membrane would make it impossible to pass into the scala tympani. But at the very top this partition is absent, and the scala vestibuli connects with the scala tympani. The imaginary object might, therefore, pass into the scala tympani, descend through two and one-half turns the scala tympani, and finally reach the round foramen which leads into the middle ear. There is, of course, stretched across this foramen a delicate membrane which prevents the perilymph from flowing into the middle ear. If the imaginary object at the round foramen were to return to the vestibule it could do so only by re-ascending the scala tympani to the top of the cochlea, passing into the scala vestibuli and descending the scala vestibuli to the vestibule.

3.—*The Path of a Sound Wave Through the Inner Ear.* Perhaps it will be helpful in understanding the reason for this arrangement to follow a sound wave after it has reached the oval foramen by way of the stapes.

The wave is (1) transmitted by the movements of the stapes to the perilymph of the vestibule. In the perilymph the vibrations run in every direction, but, as we shall find that the perception of sound occurs in the cochlea, we are interested only with those vibrations which reach it. The vibrations which reach the semicircular canals do not, as far as we know, figure in any way in hearing and so may be disregarded. From the vestibule the sound goes, (2) up the continuation of the perilymph through the scala vestibuli of the cochlea to the top of same. (3) At the top

where the partition is missing the sound wave reaches the scala tympani and, (4) then descends the scala tympani to the round foramen by the movements of the membrane of which it is (5) finally led back into the middle ear and so lost. A sound wave does not, therefore, go into the internal ear to be there lost, but is passed *through* the same in such a way, that the reflection of a sound wave backwards in the form of an echo is prevented. It is evident that if one vibration after another should run into the perilymph, that unless these vibrations could pass out again they would be reflected back, and meeting new vibrations entering produce a confusion that would preclude the possibility of distinctly hearing. We shall see that the ear perceives these waves as they pass unhindered by.

Having examined the bony labyrinth it is possible to place in it more intelligently the real sensory or membranous part.

THE MEMBRANOUS EAR.

In the vestibule the membranous ear consists of two sac-like expansions connected by means of a narrow bridge. The sac nearest the cochlea is called the *sacculus*, the one nearest the semicircular canals the *utricle*. The sacculus and utricle float in the perilymph. They are hollow structures and are filled with a liquid called the endolymph. As the membranous ear is an entirely closed structure the perilymph around it and the endolymph within it are in no place in direct communication.

Arising from the utricle are three membranous semicircular canals which pass through the bony semicircular canals, occupying, however, only a relatively small part of the space of these. On one limb of each semicircular canal near to where it arises from the utricle there is a marked expansion called an *ampulla*. This dilatation is shared by the bony canal as well.

Connected with the sacculus there is a small tube which leads into the cochlea and extends to the very top. This is the *membranous cochlea*. It is really nothing but a tube-

like extension of the sacculus coiled two and one-half times, and in the bony cochlea lies just above the basilar membrane. It is in the cochlea triangular in form, the basilar

Fig. 159.—THE MEMBRANOUS INNER EAR.

u, utricle with contained macula acustica; s, sacculus with contained macula acustica; s. s. c, superior, p. s. c, posterior, e. s. c, external semicircular canal, the crista acustica being indicated in each ampulla; c. r, canalis reunions, connecting the membranous cochlea with the sacculus; c. c, the membranous cochlea; s. e, the ductus endolymphaticus. This duct serves to connect the utricle and the sacculus, and ends blind below in the sac-like enlargement called the saccus endolymphaticus.

membrane being the floor of it, and the membrane of Reissner being one of the sides. It lies, therefore, between the scala tympani and the scala vestibuli, and for that reason is frequently called the *scala media*. The scala media is filled

Fig. 160.—SECTION OF THE LEFT COCHLEA OF A CHILD, SIX TIMES NATURAL SIZE, SHOWING THE MODIOLUS, THE SCALA TYMPANI, SCALA VESTIBULI, AND SCALA MEDIA. (After Reichert.)

with endolymph, which is in direct continuity with the endolymph in the sacculus, but is entirely shut off from the perilymph around it. In this membranous cochlea we find the

organs of Corti and the endings of the nerves and so the points in the ear where physical vibrations give rise to nervous sensations.

THE HISTOLOGY OF THE MEMBRANOUS LABYRINTH.

1.—*Sacculus and Utriculus*. Both sacculus and utriculus are hollow, sac-like structures filled with endolymph. There is found, however, at those points on the sacculus and utriculus where the auditory nerve enters them a small projection called the *macula acustica*. This *macula acustica* is a kind of a projection inward, on the top of which there are the auditory hairs projecting into the endolymph. These auditory hairs are really continuations of the auditory cells which are found in the *macula acustica* and which are connected at their bases directly with the auditory nerve.

In the mucilaginous matrix between these auditory cells there are imbedded very small stones called the *otoliths*. These *otoliths* are composed of calcium carbonate and their function is probably to help stimulate the nerve cells by their inertia when set in motion by the endolymph. The *otoliths* in man are only microscopic crystals, but in the fishes and some of the invertebrates they become quite large, a half inch or more in diameter.

2.—*Semicircular Canals*. Connected with the utriculus are three semicircular canals each of which possesses on one of its limbs an enlargement known as the ampulla. A cross-section of such an ampulla shows, projecting into the interior of it the *crista acustica*. This projects inward relatively much further than the *macula acustica* just referred to.

An epithelium of auditory cells connected with the auditory nerve covers the *crista*. Delicate hairs from these project into the surrounding endolymph. At other portions of the semicircular canal it is a smooth tube lined with ordinary epithelium, and has at these portions probably no definite sensory functions.

THE MINUTE STRUCTURE OF THE MEMBRANOUS COCHLEA.

The position of the membranous cochlea between the scala vestibuli and scala tympani has been referred to. Its shape as a triangular tube running from the sacculus to the top of the cochlea has been stated. Speaking approximately its boundaries are as follows: The upper side formed by the membrane of Reissner separates it from the scala vestibuli; the lower side is formed by the basilar membrane and a part of the lamina spiralis, these two separating it from the scala tympani. Its outer wall is formed by the wall of the bony cochlea itself.

1.—*Basilar Membrane.* The essential structure in this membranous cochlea is the basilar membrane. This, although called a membrane, really consists of a number of strings of varying length stretched from the edge of the lamina spiralis to the outer wall. These strings are shortest at the base of the cochlea and become gradually longer towards the top. If this basilar membrane were removed from the cochlea and straightened out it would have the appearance given in Figure 161. Such a structure suggests at once various kinds of musical instruments built on this plan. The sounding-board of a piano is fashioned after

Fig. 161.—DIAGRAM SHOWING THE GRADUAL LENGTHENING OF THE CORDS IN THE BASILAR MEMBRANE, *a, d, a, d'*, AND THE CORRESPONDING INCREASE IN THE WIDTH OF THE ORGANS OF CORTI, *a, b, a, b'*.

such a plan, the shorter strings of the board representing the treble notes, the longer ones the bass notes. This

basilar membrane consists of about 3,000 such strings laid side by side. Other things being equal the lengths of these individual strings will determine the pitch of their vibrations, so that the basilar membrane has its high strings near the base of the cochlea, its low ones near the top. This basilar membrane is, in fact, the sounding-board of the ear, and the various strings of this sounding-board are set up in sympathetic vibrations by the sound waves which pass through the cochlea.

It will be remembered that the sound waves from the vestibule ascend the cochlea through the scala vestibuli, and while ascending this they do not affect the basilar mem-

Fig. 162.—SECTION ACROSS THE BASAL TURN OF THE HUMAN COCHLEA. (After Retzius.)

D. C., scala media; *s. v.*, scala vestibuli; *s. t.*, scala tympani; *R*, membrane of Reissner; *Mt*, tectorial membrane; *b. m.*, basilar membrane; *t. C.*, tunnel formed by the rods of Corti; *n*, nerve; *sp. l.*, spiral lamina; *s. sp.*, sulcus spiralis; *l. sp.*, spiral ligament; *l.*, limbus; *h. i.*, inner hair cells; *h. e.*, outer hair cells, with hairs from same projecting through the reticular membrane.

brane, as the membrane of Reissner intercepts. At the top of the cochlea the sound passes into the scala tympani, and

while descending the scala tympani the vibrating perilymph in the same is in direct contact with the basilar membrane and at this point sets into vibrations, in a sympathetic way already explained, the strings which are attuned to that particular vibration. In other words, the human ear is but the second tuning-fork set into motion by the first one. It is the piano that responds again with the notes sung into it.

The student will have gone far in understanding the exact manner of hearing when he has made clear to himself the complete analogy of the basilar membrane to a musical sounding-board on which are stretched as many as 3,000 differently attuned strings. It must be noticed further that the proper vibrations of these strings is a purely physical result, and would happen in a dead ear or an ear constructed out of metal almost as readily as in a living ear.

2.—*Rods of Corti*. Standing on this basilar membrane are two rows of rods which lean towards each other in such a way as to form a tunnel underneath. These two series of rods are called the *rods of Corti*. One series rests on the basilar membrane just at the point where it is attached to the lamina spiralis; the other, or outer rods, rest upon the basilar membrane itself. The rods next to the lamina spiralis, the inner rods, seem to be more slender and are also more numerous than the outer rods, the numbers being about 6,000 and 4,500 respectively.

At the base of the cochlea the rods of Corti are higher but stand closer together than they do towards the top, where they are lower and wider. (See Figure 161.)

3.—*Reticular Membrane*. Where the two sets of rods meet there is attached a membrane which extends out horizontally some distance over the basilar membrane. This membrane is called the *reticular membrane*, the name being derived from the fact that it is pierced with very many small openings through which the hair endings of the auditory cells beneath extend.

4.—*Tectorium*. From the lamina spiralis there extends a membrane over the rods of Corti and reticular membrane called the *tectorium* or tectorial membrane. It serves for purposes of protection to these delicate structures underneath. The groove formed between the lower portions of the lamina spiralis and the tectorial membrane is called the *sulcus spiralis*.

Fig. 163.—STRUCTURE OF A SINGLE ORGAN OF CORTI, AND TO THE RIGHT THEIR ARRANGEMENT INTO A SERIES, SUPPORTING THE FENESTRATED RETICULAR MEMBRANE.

i, internal rod; e, external rod; †, articulation of the two rods; ††, beginning of reticular membrane; n, nerve; b, basilar membrane.

5.—*Auditory Hairs*. This sulcus spiralis is lined with cuboidal cells, which are continued over the margin of the basilar membrane as columnar cells, some of which bear on their upper end short, stiff hairs. These cells between the rods of Corti and the sulcus spiralis are termed the *inner* hair-cells. Similar cuboidal cells are found on the basilar membrane beyond the rods of Corti, which cells end in delicate stiff hairs that project through the openings in the reticular membrane. These are called the *outer* hair-cells.

Where the basilar membrane joins the outer wall of the cochlea these cells lose their cuboidal appearance and gradually shade off into the ordinary epithelium which lines the outer wall and the inner wall of the membrane of Reissner. These outer and inner hair-cells or auditory cells are connected at their bases with nerve fibers from the auditory nerve reaching them through the lamina spiralis. The reader to orient himself properly must study the description just given in terms of the accompanying diagrams.

THE FUNCTION OF THE INDIVIDUAL PARTS OF THE
MEMBRANOUS EAR.

1.—*Utriculus, Saculus, and Semicircular Canals.* Regular auditory functions were formerly attributed to these. The suggestion was even made that these structures aided in the perception of noises, while to the cochlea was referred the perception of musical sounds. Such a distinction is, of course, absurd at once, the difference between noise and music being a physical and not a physiological one. Later Florens and Goltz pointed out that these structures were really not concerned at all with the direct sense of hearing, but that they figured as organs of equilibrium. Animals from which the semicircular canals have been removed show the greatest difficulty in standing still or moving readily and with precision. They seem to be unable to tell the position of their bodies and show all the symptoms ordinarily associated with intense dizziness. An animal so robbed of these structures performs the most senseless and awkward movements. It seems perfectly helpless and is scarcely able to eat unaided. The question then arises, in what manner these structures figure as equilibrium organs.

First. The three semicircular canals are arranged like the three diameters of a cube, and so there is no motion possible which does not fall in the plane of one or more of these canals.

Second. These canals are filled with endolymph which is in communication at both ends with the utriculus and so is able to circulate somewhat through these canals.

Third. A movement of the head in any direction will cause a backward flow of the endolymph in the semicircular canal affected, due to the inertia of that liquid, just as in the starting of a train the passengers by their inertia are thrown backwards. This backward motion of the endolymph affects the hairs projecting into it in the ampulla somewhat like a stream of air over a field of grain, and in

this way a sensation is produced which in the mind is interpreted in terms of position or movement. If, however, the motion in a certain direction should continue, the endolymph inside would soon adjust itself to that motion, just as after a train has started the passengers no longer feel a tendency to be thrown backwards. A sudden stopping now of the train throws the passengers violently forward. So a sudden stopping of the motion of the body, say for instance from a circular motion, will cause the endolymph on account of its inertia to be thrown forwards and in this way affect the projecting hair cells and give rise to a sensation of motion. Possibly this is the explanation of the dizziness which results when a rotary motion of the body suddenly ceases. To the individual it seems that he is still moving.

One point in favor of the view that these organs are wholly organs of equilibrium is the fact that the perception of all sounds can be satisfactorily explained in the cochlea, and so there is no necessity to begin with for attributing auditory sensations to these structures. On the other hand, however, none of the invertebrates have a cochlea, and yet it would be entirely wrong to think that these animals are without the sense of hearing. Evidently, therefore, in the invertebrates at least, structures very analagous indeed to utricle, saccule and ampulla are directly concerned in the perception of sound, and it may be possible that even in the human being this property has not been entirely lost, but has simply been overshadowed by the addition of a new structure to the ear, the cochlea.

2.—*The Function of the Cochlea.* The anatomy of the cochlea readily shows how a vibration descending the scala tympani is brought in direct contact with the basilar membrane, and how there by sympathetic vibrations it sets into motion some one of the many strings which is attuned to it. Arrangement is thus made in purely physical ways to set in vibration the proper string in any case, but it is an equal physical necessity that such vibration should cease as soon as the sound producing it ceases. It would, of course, be

very undesirable to have the basilar string in the ear vibrate after the sound producing it has ceased. Short, sharp staccato notes would be an impossibility and there would result in the ear a blending and running together of sounds which would preclude the possibility of fine music. For this reason there are placed dampers on these strings, much after the fashion of dampers on pianos. The rods of Corti seem to have this function. Resting continually on the basilar membrane they so weigh down these strings as to make them cease their vibrations as soon as the force beneath them producing the vibration has ceased. Just as in the case of a piano the string is brought to quiet when the pedal is on, as soon as the finger is taken from the key.

Up to this point everything in connection with the ear has been purely physical. It would happen in a dead ear as readily as in a living one provided the tissues were left intact, but there now remains the necessity for some kind of an arrangement by means of which the vibrations of these strings in the ear may be communicated to the brain. This is accomplished by means of the auditory cells which stand on the basilar membrane and which are directly connected with the auditory nerve.

When a certain string of the basilar membrane is set in motion it is evident that the hair cells resting on it will be moved up and down with it, and possibly this vibratory motion of the hair cells serves to originate a nervous impulse which is then along the ordinary channels sent to the brain and there interpreted as sound.

A second possibility exists. The long stiff hairs which are found projecting from the tops of these auditory cells pass through little perforations in the reticular membrane, and it may be that when these nervous cells move up and down with the vibrations of the cord these delicate hairs are rubbed against the reticular membrane and so produce a friction which serves to originate a nervous impulse, which then, as in the other case, finally gives rise to the perception of sound. That it must be either the movement of the

cells up and down or this friction of their delicate hairs in the reticular membrane, or possibly both of these which serve as a stimulus for the nervous impulse, is beyond question.

Here is the point at which the physical vibrations give rise to physiological, that is, nervous impulses, but it must be borne in mind after all that the real conscious appreciation of sound occurs only in the auditory centers in the brain. Sound is a purely psychological experience, and the ear and the nerves leading from it to the brain serve merely as accessory pieces of apparatus to call into being these psychical acts.

Very few sounds, however, are so simple as to affect but a single string of the basilar membrane. Most sounds are composite sounds (hence their quality) and frequently composite sounds in turn are blended into harmonies. The ear, however, has the ability to perceive all the individual sounds that enter into such a composition and so we must imagine that in the perception of the concert note there are as many strings of the basilar membrane thrown into vibration as there are individual component notes in the concert. The ear is even able to analyze such a concert note so carefully that it may follow some of the individual notes in it. No one finds it difficult when hearing the rendition of an orchestral piece of music to follow a certain instrument, or in a chorus to listen with special attention to a certain voice. This analysis is possible because in the basilar membrane as many individual strings are affected as there are such component notes.

A somewhat interesting question arises when we remember that although the ear has only about 3,000 strings it is able to perceive many more than 3,000 pitches. This may seem at first inexplicable. Possibly the explanation may consist in assuming that when a pitch is sounded which has not its direct counterpart in the ear but lies between the pitches of two adjoining strings, it will affect both of them, and this possible blending may give rise to a new

perception of pitch. It is even possible to imagine that the relative strength with which the two adjoining strings are affected will give rise to a corresponding series of intermediate pitches.

THE LOCALIZATION OF SOUND.

The ability which we possess to determine the direction from which a sound comes is an acquired ability. In localizing a sound we instinctively move the head through a series of positions and try to determine in which position the sound is clearest. Having once found this position we have learned by experience in which direction we must then look. When the head is held perfectly immovable the localization of sound is very difficult indeed; in fact, it is almost impossible unless, of course, the sounds be so near that the difference in the acuteness of hearing between the two ears gives us a clue as to its direction. When a sound is familiar we determine its distance by its strength. It is, however, a purely subjective inference which it is possible to vary artificially, as for instance on the stage, when by soft playing, distance is suggested, while the gradual strengthening of the tones is interpreted as a movement of the sources of music towards the hearer.

In the ear there are sometimes perceived sounds which are not produced by regular sound vibrations. Such sounds are, for instance, the buzzing of the ears produced by the vibrations of air in the external meatus, when this air has been separated from the external atmosphere by bits of wax in the meatus, or by vibrations in the air of the middle ear, caused by an unnatural closing of the Eustachian tube. Beating sensations are usually caused by the pulsations of the arteries in the external meatus. Sensations of friction no doubt find their explanation in the circulation of the blood, while the peculiar ringing of the ears which some people are able to produce at will, especially when they contract the muscles of mastication, is explained by some as a contraction of the tensor tympani, and so a stretching

of the tympanic membrane, by others as a voluntary opening of the Eustachian tube.

Finally, it is of interest to reflect that the two ears are as a rule attuned alike, at least so nearly alike that ordinarily we perceive a note in unison. It not infrequently happens, however, that there is such a difference in the two ears as to lead to the perception of the same sound at different pitches, a pathological condition which when aggravated leads to the most serious results in the appreciation of tones. No less remarkable than the complete harmony of the two ears is the continuance of such harmony through all the vicissitudes of a person's life. Few are the instruments, indeed, which do not need repeated attention in order to hold them at their proper pitches. In the basilar membrane of the ear, however, this attunement seems not only one of remarkable operation to begin with, but practically never requires a secondary interference. Its superiority to all forms of artificial musical instruments in the number of notes which it is able to perceive, in the exactness with which it catches and reproduces all the varied forms of the sounds which reach it, and in the accuracy with which it remains in perfect attunement, may well awaken our wonder and admiration.

CHAPTER XXIII.

THE EYE AND THE PHYSIOLOGY OF VISION.

That the eye is the seat of vision is a bit of knowledge as old possibly as humanity, but it was not until 1602, when Kepler compared the human eye with the camera obscura, that any considerable attempt was made in the explanation of its function. Some time previous Porta had invented the camera obscura, and so it was but a natural step for Kepler to make this the basis for his explanation of the eye. Kepler's explanation was practically nothing more than merely the statement of such an analogy and did not deal with specific details. A few years later, 1609, the Jesuit priest Scheiner noted the inversion of the image on the retina, and made the further important discovery that the pupil contracted or expanded with the varying accommodation of the eye. In 1695 the optician Huyghens constructed an artificial eye and demonstrated on the same the action of spectacles. During the next century nothing seemed to be added to the knowledge of the eye. In 1801 Young (the founder of the present Young-Helmholtz Theory of Vision) noted and explained astigmatism. Long-sight and short-sight had been previously observed, and Huyghens had actually explained the action of spectacles in remedying these defects.

Up to the beginning of this century, and even later, nothing was known of the manner in which the eye was accommodated for far and near. The necessity for such a power of accommodation had been noted by Kepler, and Descartes had actually suggested the thought that the power of accommodation resulted from the ability of the lens to change its form, but it was not until 1801 that Young demonstrated this change in experiments on his own

eyes. Objectively this change in the form of the lens was demonstrated by the reflection of images from the surfaces of the lens, by Langenbeck in 1849, and verified by Helmholtz in 1853. The ciliary muscles had been noted by Brücke in 1846, and in 1856 Helmholtz attributed the motor agency in accommodation to this muscle, and forwarded the theory of accommodation as it still stands. The innervation of this muscle was discovered by Hensen and Völckers in 1868. The finer structure of the retina was worked out by H. Müller's researches on the eye, 1855, although as early as 1851 Helmholtz had designated the rods and cones as the points sensitive to light. The blind spot had been discovered by Mariotte as early as 1668. In 1876 the vision purple found in the rods was discovered by Boll.

Our knowledge of the physiology of color sensations has been of slow growth. In 1657 the celebrated Newton in his studies on the spectrum discovered the different refractive indices of the different colors and their composition into white light. In 1690 Huyghens proposed the wave theory of light, while in 1746 Euler demonstrated that the difference in colors depends on the rate of light vibrations, or what is the same thing, the length of the waves. A theory of color sensations was advanced by Young in 1807 which modified by Helmholtz is to-day possibly still the best explanation at hand. The Young-Helmholtz theory does not, however, offer a satisfactory explanation for several observed facts, and to include these a second entirely different theory was advanced by Ewald Hering in 1872. Quite a number of other observers have added to our knowledge on this subject. Such has been in briefest outline the path of the discoveries which have led to our present understanding of the eye. It may be in place at this point to add that there remains very much still unexplained about the eye, and that there are few subjects in physiology concerning which additional information is more sorely wanted.

SOME OF THE ELEMENTARY PHYSICAL CONCEPTIONS OF LIGHT
NECESSARY TO A PROPER UNDERSTANDING OF THE
PHYSIOLOGY OF THE EYE.

The eye is a complicated piece of apparatus especially designed to translate light impressions into nervous impressions. Its construction is for a specific purpose and its anatomy dependent upon the physical properties of the light it is to translate. It is, therefore, entirely impossible to understand the *raison d'être* of the eye's structure without having an elementary conception at least of some of the physical properties of light.

1.—*The Nature of Light.* For a long time light was looked upon as small particles of matter projected in straight lines from a luminous body. These little particles passed into the eye, and there in some way produced the sensation of light. A lamp, therefore, would be something like a spherical Gatling-gun throwing its missiles in every conceivable direction at a very great velocity. These particles were looked upon as exceedingly small and light, and able to penetrate even such hard substances as glass.

This material projection of light had soon to be abandoned as thoroughly unable to explain all of the phenomena at hand. As a result of more exacting study there was advanced soon what is now familiarly known as the undulatory theory of light, the theory which conceives of light as oscillations or waves of some suitable medium. This medium is the ether, possibly a hypothetical substance, and yet one to the actual existence of which we are driven by the necessity of the mind.

This ether is a very light imponderable medium offering little if any resistance to objects moving through it. It not only pervades all space, but seems also to pervade many solid objects, such as glass and others which we are wont to call transparent. Rays of light are conceived as vibrations passing through this medium, in which the actual particles of the medium move but little out of their place,

while the wave, however, transmitted from particle to particle travels with inconceivable rapidity. Speaking generally, light is like sound—a wave motion, but these waves differ in several respects from each other. In the case of light the medium is ether and in sound air, or water, or solids. The rapidity of transmission is very different, and the form of the wave is quite unlike that of the sound wave. In the transmission of a sound wave through the air the particles of air carrying the wave move backwards and forwards in the direction in which the sound is moving. In light, however, the individual particles of ether move at right angles to the direction of the ray of light. If it were possible to picture a ray of light approaching one it would, using a very rough analogy indeed, look somewhat like a wheel, the hub being the line of direction, while the individual spokes would represent the directions in which the particles of ether are thrown by the wave at that point. If one could now think of such a wheel squarely approaching one and imagine the spokes radiating from it in every direction to be rapidly drawn into the hub and projected again, one would have a very rough idea of the picture of an approaching wave of light.

2.—*The Rate of Transmission.* It was impossible for a long time to make actual calculations of the rate with which a ray of light travels, as its rapidity was so great that for all practical purposes it was instantaneous. The opportunity of measuring light passing through immense distances presented itself when the phases of the satellites of Jupiter were carefully noted. When the earth is between the sun and Jupiter, that is as close to Jupiter as its orbit permits, the time for the phases of one of Jupiter's satellites was carefully determined. Six months later the earth is, of course, further removed from Jupiter by the distance of the earth's orbit. Calculations now showed that the phases of the satellite in question were a little over sixteen minutes slow. The explanation of the sixteen minutes' tardiness consisted in attributing this loss of time to the time required by the light

to pass the added distance of the earth's orbit. In other words, it took a ray of light a little over sixteen minutes to cross the earth's orbit, a distance of some one hundred and eighty million miles. This makes the distance traveled per second about 186,000 miles.

Thus, a ray of light would have a sufficient speed to travel around the earth's surface about seven or eight times between two successive ticks of a second hand.

3.—*The Number of Vibrations in Waves of Light.* If light is a wave motion the problem presents itself of having the number of vibrations per second measured. Without going into the physical explanation of the manner in which this is accomplished, save the statement that such measurements have been made and the number of vibrations per second determined with relative accuracy, the interesting fact at once comes to light that the number of vibrations determines the color of the light just as in the case of sound the number of vibrations determines the pitch. The pitch of a light is its color. The lowest pitch in light visible to the eye is red; the highest pitch is violet. When the vibrations become less frequent than those in red or more numerous than those in violet they do not affect the eye and seem like perfect darkness. This darkness below the red and above the violet is, however, not a physical darkness; it is a physiological darkness. Even though the etherial vibrations are there the physiological capacity of the eye is not large enough to include them.

Using approximate figures only, there are in red light 400,000,000,000,000 per second; in violet, 800,000,000,000,000. The lowest base note in light consists of four hundred trillions; the highest note of eight hundred trillions per second. Between these two extreme pitches of color are the other colors of the spectrum. Thus green, which is about half way between the red and violet, has in the neighborhood of six hundred trillions.

4.—*The Spectrum.* Ordinary sunlight, the ordinary light of the day, is what we usually designate "white"

light. This white light is not a simple light but consists of all the vibrations from the red to the violet. In other words, white light is a concert of all the pitches of light. In music we are able to analyze the individual sounds that go into a complicated harmony, but in light the eye is unable to make such an analysis, and this combination of all of the colors of the spectrum is perceived as one color and called white.

By means of a prism it is possible to separate this white light, to analyze it, and get each color by itself. The result of such a procedure is the spectrum familiar to every one, if not in the laboratory, at least in the rainbow. By means of such a prism the colors are strung out, from the red at one end to the violet at the other, and the position of each color is determined by the number of vibrations per second which it has. Commonly we say that in this scale we are able to perceive seven distinct colors. These are: red, orange, yellow, green, blue, indigo, violet.

Reference to the number of vibrations in red light and violet light shows that violet light is just an octave above red light. It possesses just about twice the number of vibrations, and it is extremely interesting to note that at the violet end the red reappears. In fact, violet is nothing but the blue, with which is mixed a little red, possibly the red of the next octave. It is apparent, therefore, that our range of vision extends over but one octave of colors, from the red at the lower end to the red at the upper end, where it reappears to blend with the blue forming the violet. What the color sensations would be if the range of vision should extend over more than one octave it is entirely impossible to say. If, however, they should be reproductions of the first octave one can see that nothing would be gained by their presence as far as new colors are concerned, and as the eye is perfectly unable to analyze a compound color, is unable to perceive its inherent harmony, there is but an added reason for the limitation of the range of vision to a single octave.

The seven colors of the spectrum are usually spoken of as the fundamental colors, because by the mixture of two or more of these it is possible to produce all the other colors. Thus the proper combination of all seven forms white; the absence of all of them gives the perception black. Black is in light what a rest is in music, but while in the ear a rest is perceived as the absence of any positive sensation, in the eye an absence of all light is interpreted as a positive sensation, and so black seems to be a definite color. By mixing any of the fundamental colors with white we get the varying tints of these colors; by mixing them with black the corresponding shades. Thus red and white make pink, red and black brown; green and white produce light green, green and black olive, blue and white the light blues, blue and black the blue blacks. Red and blue form purple, purple and green produce white. Mixing colors near each other in the spectrum produces an intervening color. Thus red and yellow form orange.

It must be especially borne in mind that in all instances of the combinations just given the sensations are mixed and not pigments. Thus on a color disk partly red and partly blue the color purple will arise upon a rapid rotation of that disk. If one should mix pigments quite a different result would occur. To mix red and blue combined in certain proportions produces not purple at all, as when sensations are mixed, but produces green, the explanation of which will be given further on.

5.—*Complementary Colors.* Two colors (sensations) which when mixed together produce white, are spoken of as complementary colors. For each color of the spectrum it is possible, if the color purple be added, to find a second color complementary to it. The relations of these colors are given in Figure 164, where the colors of the spectrum are so arranged that those directly opposite each other from the point called white are complementary. The use of indigo or blueing in the process of laundering con-

sists in neutralizing the yellow of the linen, yellow and indigo forming white.

Fig. 164.—GRAPHIC REPRESENTATION OF THE FORMATION OF WHITE OUT OF THE SERIES OF COMPLEMENTARY COLORS.

The line from the green should be continued to the purple, as green and purple are complementary colors.

6.—*The Colors of Objects by Transmitted or Reflected Light.* So far the colors have been described as vibrations of ether proceeding from a luminous body, and by the number of such vibrations per second the light will have its color determined. But most bodies are not luminous; a window pane is not luminous but transmits light through it; the wall of a house is not luminous but is seen only by the light which it reflects from some luminous source. Ordinarily this transmitted or reflected light is sunlight. Even though the rays of the sun do not shine directly into the room, some of the rays have been reflected by the grass or sky, or objects on the ground in such a way as to reach the wall in question, and being reflected from this in turn into the eye, the wall becomes visible.

The question then presents itself, what determines the color of such a transparent piece of glass or of the opaque wall?

First, objects colored by transmitted light. A red window pane seems red because it has absorbed all the other colors in the light which passes through it, but transmits unhindered the red light reaching it. Like the gold digger

who picks out of the sands the yellow gold, but allows the white sands to be washed through his fingers, so this window pane picks out all the colors of the spectrum, while the red color, like the sand in the analogy, it allows to pass through. We can easily understand how a boy looking over an assortment of marbles would pick out for his own use and put into his pocket all those of certain desirable colors and reject possibly all those of some, to him, unsatisfactory color. So this window pane picks out and absorbs from the composition of colors which reach it in the white light certain colors, while it rejects, that is, allows to pass without hindrance, the red light which falling into the eye finally arouses there the corresponding sensation. It is evident that such a window pane could look red only when red light reached it, since that is the only light it allows to pass through. If blue light alone should reach it the blue would be entirely absorbed and the result would be no light at all traversing it, the window pane would look black. One may easily try the experiment of looking through a piece of red glass at an intensely blue object. The red glass is opaque to the blue. A similar experiment would be to take a red glass and a blue glass and let a beam of light pass through both. As this beam of white light passes through the blue glass plate all the red and yellow would be absorbed and nothing but the blue be permitted to pass. But blue light is absorbed by the red pane, which allows only red light to pass through, but as all the red light was absorbed by the blue plate, no light at all passes through. The two transparent glasses act like an opaque object.

Second, what is the explanation of the color of the objects around us, such as the cover of a book, the tint of a ribbon, or the shade of a paint? The explanation is similar to that given in the case of transmitted light. White light falls on the ribbon, and if this ribbon should reflect all the light that it received, it too, would appear white. But the ribbon absorbs some of the colors and reflects only those colors which it cannot absorb. In the case of the red ribbon,

green, blue, violet, and even some yellow are absorbed, and so only the red light remains to be reflected. A rather far-fetched analogy might be found in throwing against a wall a handful of different objects, nearly all of them very sticky indeed, but mixed with these several elastic rubber balls. If such a handful of objects were hurled against a wall, not all of them would be reflected. Most of the sticky objects would remain attached to the wall, and possibly the rubber balls alone be reflected. So in the sunlight, which is a mixture of the fundamental colors, practically all of the colors are absorbed by the ribbon, while the red, like the rubber ball in the analogy, is reflected, and as we judge of the color of an object by the light which comes from it, we designate it as red. As a matter of fact, however, the color of an object by reflected light is always the color which it has rejected.

7.—*The Refraction of Light and the Property of Lenses.* Light passes in straight lines through a medium of uniform density. If, however, it passes from a less dense to a more dense medium it is bent from its course. Such a bending of rays of light is called refraction, and upon this property of light depends the use of lenses. A lens is nothing more than a transparent medium of greater density than the air, and so will bend the rays of light from their original direction. It would be entirely out of place in this discussion to go into detail in the matter of refraction, and it will suffice to call attention to the ordinary kinds of lenses and the manner in which they refract the light.

Convex lenses, either convex on both sides (double convex lens) or plain on one side (single convex lens) bend the rays of light together, and if the lens be a fairly good one, all the rays in a beam of light may be finally bent so as to meet at a certain point back of the lens known as the focus. The amount of the bending of the rays will depend, other things being equal, upon the convexity of the lens, being greater, the greater the convexity. Illustrations of such results are familiar to ever one in the ordinary burning

glasses, by means of which the parallel rays of the sun are concentrated at one point sufficiently to start ignition.

If the lens be concave, either on both sides (double concave) or on one side (single concave) the rays of light will be bent apart; that is, scattered. This action of lenses will be more evident by comparison of Figures 165 and 166, where the course of rays of light through such lenses is shown by a series of lines. Some lenses may be concave on one side and convex on the other, called concavo-convex lenses, and such lenses will either converge the light or scatter the light, according as the convexity is greater or less than the concavity.

Fig. 165.—TO SHOW THE CONVERGING ACTION OF A CONVEX LENS.

Fig. 166.—TO SHOW THE DISPERSIVE ACTION OF A CONCAVE LENS.

F, the focus at which the dispersed rays would meet if continued.

For the purpose of understanding the eye it is especially desirable to bear in mind the fact that the convexity of a lens will determine the extent of the refraction of the light through it and also the position of a focus back of it. The more convex the lens is the closer will be the focus behind the lens, the less convex it is the further removed from the lens will be this focus. Upon these simple considerations

of the refraction of light is based the use of spectacles, and even the use of the eye itself, this containing within itself several refracting media which obey in every way the physical laws that govern light refraction.

8.—*The Formation of Images by Lenses.* By means of a good lens or a system of lenses there may be produced an image of an object placed in front of the lens. The microscope, the telescope and the photograph camera attest this fact. In the camera a sensitive plate is put back of the lens in such a position that the image produced by the lens falls directly on it, and there in chemical ways leaves its impress on the sensitive plate. There is in the eye an exactly analogous result, the eye being in practically every particular a high grade camera in which the sensitive plate is replaced by the still more sensitive retina, and in order to perceive objects clearly the image produced by the lens and humors of the eye must fall directly upon the retina. The point under explanation here is to show under what circumstances an image arises. An image results when a number of rays of light emanating from the same point are so bent by a lens as to *meet* again at a certain point back of the lens. As the rays of light from any point on a luminous body radiate in every direction; that is, diverge more and more, it is evident that they would never meet unless these divergent rays should be bent together by some refracting medium; hence no image is possible when the lens is removed. The function of the lens is to collect this divergent pencil of rays from the point in question, and bend it together to meet in a corresponding point back of the lens.

If at this second point a screen be held there appears an image the exact counterpart of the object. But any object consists of but an infinite number of individual points, and so it is the function of the lens to take the divergent rays from each of these infinite points and converge them to a corresponding number of infinite points behind the lens.

In this manner there arises the complete image of the entire object. Figure 167 shows this action of the lens for two given points. Reference to it will also show that the image will be inverted. This is also true of the image on the retina.

With these physical conceptions of the nature of light and its properties we are ready to understand with more meaning the detailed anatomy of the eye.

Fig. 167.—DIAGRAM TO ILLUSTRATE THE REFLECTION AND THE REFRACTION OF LIGHT.

At A the beam of light is reflected, illuminating the arrow *ac*, at B. From all points of the arrow *ac*, the light is reflected in all directions. Two such divergent beams are shown as refracted by the convex lens *L, L*, and brought to points *a'* and *c'*, producing at these points images of the points *a, c*. As this is true for all points on *ac*, there will be a complete image at *a'c'*. The lines at *S' S'*, and *S'' S''*, show positions of screen where the image is blurred.

THE ANATOMY OF THE EYE.

While the eyeball itself contains the sensitive retina and the refracting media, and so the essential parts of the eye, it is provided with a number of appendages which make its use in vision much more efficient. On account of its sensitiveness it needs special organs for protection. A system of muscles enable it to make rapid movements, while a lachrymal apparatus protects it from an accumulation of dust and other foreign particles.

1.—*The Eyebrows.* The function of these is so apparent from every-day experience, preventing the perspiration of the forehead from running over the eyeball but turning it aside down the cheeks, that further statement is unnecessary. That they act in shading the eye is probably only exceptionally true.

2.—*The Eyelids.* Each eye is provided with two main eyelids and the remnant of a third. Of these the upper eyelid is the one which has the greatest range of motion, and by the movements of which the lachrymal secretion is being continually washed across the globe. In addition to distributing the tears it serves purposes of protection against foreign particles and for the exclusion of light when that is too intense, or when, as in sleep, it is to be excluded altogether. The functions of the upper eyelid apply to a certain extent equally to the lower eyelid.

At the edge of these eyelids are found the eyelashes, rows of hairs serving to prevent foreign particles from getting into the eye, and possibly shading the cornea. Between these hairs open the ducts of specially developed sebaceous glands, known as the *Meibomian glands*, which secrete a fatty substance specially evident in certain cases of inflammation, where this secretion becomes so excessive as to stick the eyelids together. This secretion serves not only to keep the edge of the eyelids pliable, but prevents the tears from running over the eyelids, it being a general physical fact that water does not readily flow over an oily surface. Of course in the act of crying the amount of the secretion increases so much that this oily edge no longer serves as a sufficient barrier, and so the tears stream down the cheeks.

Lining the under sides of the eyelids both upper and lower and reflected back over the front of the cornea is the *conjunctiva*. Few membranes in the body, especially those exposed to the exterior, are so richly supplied with nerves and so sensitive to all foreign objects. The explanation of placing such a very sensitive membrane under the eyelids and over the cornea lies in the fact that it prevents us from becoming careless about injurious particles reaching the eye, and so gives us no rest until the irritating object is removed.

The lifting of the upper eyelid is effected by muscles running down into the eyelid. The closing of the eye is

due to the contraction of a circular muscle which runs through the upper and lower eyelids and so encircles the open space which separates the upper from the lower lid.

In addition to the two regular eyelids there is present in man the rudiment of a third eyelid. This may be readily observed as a red vertical fold at the inner corner of the eye, and in some individuals reaching almost to the iris. This eyelid is especially developed in many animals, such as birds, and can by these animals be drawn entirely over the front of the eyeball. When so fully developed it is called the *nictitating* membrane.

In this remnant of the nictitating membrane is a small reddish elevation readily recognizable called the *caruncula lachrymalis*, consisting of a number of sebaceous glands imbedded in this fold.

3.—*The Lachrymal Apparatus.* To keep the surface of the eyeball perfectly clear and to remove particles of dust, there is provided for each eye a lachrymal apparatus consisting of a tear gland and a system of ducts.

Fig. 168.—THE LACHRYMAL APPARATUS.

1, lachrymal gland; 2, lachrymal ducts; 3, 3, the puncta lachrymalia; 4, the nasal sac; 5, the nasal duct.

The lachrymal or tear gland lies not in the inner, but in the upper and outer part of the orbit under the edge of the frontal bone. It is about the size of an almond. From this gland (which histologically is an ordinary racemose

gland), run quite a number of ducts which open in a row under the upper eyelid. From this point the secretion is washed over the front of the eye by the ordinary movements of the eyelids, such as those of winking, and so the cornea is kept moist and clear and free from dust. The secretion is finally led off by two lachrymal canals, which arise each as a small pore called the punctum lachrymalis found on each lachrymal papilla. These lachrymal papillæ are readily recognized as small reddish elevations at the inner angle of the upper and lower eyelids. The lachrymal canals soon unite, opening into the nasal duct, the upper portion of which is somewhat enlarged and called the lachrymal sac. The lower portion of the nasal duct opens into the back part of the nose chamber, and from this place the tears find their way into the throat and are swallowed. Ordinarily the amount of the secretion so poured into the throat is so slight that we take no notice of it. In violent weeping, however, the secretion may become so plentiful as to necessitate repeated acts of swallowing.

4.—*The Muscles of the Eyeball.* The rapidity and exactness with which the eyeball may be moved attest the presence of a system of eye muscles. Each globe is provided with six muscles; four of these are straight muscles and two are oblique. The straight muscles lie, one on top of the eye—the superior rectus, one below the eyeball, the inferior rectus, one on the outer side—external rectus, and the fourth on the inner side—internal rectus. It is readily seen that by means of these four muscles the globe of the eye may be turned in any direction save a rotary one. To make this motion possible there are two oblique muscles. One of these is fastened to the top of the eyeball, runs inward towards the nose, and there passes through a tendonous loop like a pulley, to be inserted near where the recti are. This is the superior oblique muscle. The inferior oblique muscle arises at the back of the orbit, near the lachrymal sac. From this point it passes slightly outwards and backwards beneath the eyeball, and is inserted

into it posteriorly. The exact movements which each of these muscles is able to produce may be readily seen from their manner of attachment.

One of the most striking things about these muscles is the harmony with which they work. In normal eyes the co-ordination is almost perfect. When, however, one or more of these muscles cease to be so carefully adjusted, either as a cause of paralysis or of other causes, there results what is familiarly called the "squint," which is a right or a left, an external or internal squint, according to the muscle affected. An exaggerated condition of a squint is finally termed "cross-eyed."

Fig. 169.—SEMIDIAGRAMMATIC SECTION OF THE EYEBALL.
(The reader will find the explanation of the section in the text.)

5.—*The Globe of the Eye.* The globe of the eye is a spherical body an inch or more in diameter, with a large

portion of it visible from the outside. It is not evenly spherical, but consists of segments of two spheres, the larger sphere composing most of the eyeball, the smaller sphere forming the cornea.

The globe is a completely closed ball pierced only at one end, where the optic nerve and the blood-vessels for the retina enter it. The walls are, of course, provided with blood-vessels and nerves which enter it, but consist almost wholly of very tough connective tissue so strong that in the case of a beef's eye one may be able to stand on an eye without breaking these coats.

In a general way these coats are described as consisting of three, called the outer or sclerotic coat, the middle or choroid coat, and the inner coat or the retina.

Enclosed within these coats are three refracting media; the aqueous humor, the crystalline lens, and the vitreous humor.

6.—*Sclerotic Coat.* The sclerotic coat is the outer coat and is by far the strongest and toughest. It consists almost entirely of closely packed white connective tissue. This coat is visible from the outside as the white of the eye. Immediately in front of the eyeball this coat is transparent and is called the *cornea*. The sphericity of the cornea is greater than that of the eyeball itself.

The sclerotic coat covers the entire eye save at the back where the optic nerve and the retinal blood-vessels pass through it. The cornea is covered over in front with the conjunctiva, and on its inner side is lined with a layer of epithelial cells called the membrane of Descemet.

7.—*The Choroid Coat.* Immediately beneath the sclerotic coat is the choroid coat. This is not nearly so tough as the sclerotic, but is much more vascular and readily recognizable in the dissection of the eye by the black pigment which it contains. It is, in fact, the choroid coat to which the black inner walls of the eyeball are due, and the presence of this pigment in the choroid explains largely its

function. All good optical instruments are painted black inside, so as to do away with the possibility of reflection from the walls, which would materially interfere with the clearness of the image. The cornea is not in contact with the choroid, but at this point the sclerotic coat and the choroid are separated and so a space produced which is filled with a watery liquid called the *aqueous humor*. The pigment of the choroid is also different at this place, and instead of being black is brown or blue, or whatever other color we find the eyes to have. This colored portion of the choroid coat seen through the cornea is called the *iris*.

Just in the middle line of the eyeball the iris has an opening known as the *pupil*, and visible on the eye as a dark disk within the iris. This dark disk is really a hole, but seems dark because no light comes out of it, just as an opening into a mine would seem dark if there were no light beneath.

Within the choroid coat lies the *retina*. The retina is but an expansion of the optic nerve and does not run entirely around the eye. The impossibility of throwing an image on the forward portions of the inner wall of the eye would render useless the extension of the retina so far.

Filling the large posterior chamber is the *vitreous humor*, a transparent glassy-looking liquid having about the consistency of the white of an egg. This vitreous humor is enclosed in a delicate membrane extending all around it, known as the *hyaloid membrane*. This membrane seems a single layer in most portions, but towards the front it divides into two layers, and in the space so formed there is imbedded the rather large *crystalline lens*.

As the eyeball is distended even to a slight pressure with the vitreous humor, all the coats are held in place and a collapse of the eyeball is prevented. In fact, the pressure of the vitreous humor in the hyaloid membrane is normally such as to stretch this somewhat, and as the lens is imbedded between the layers of this membrane it is by the stretching of this hyaloid membrane always in a state of

compression, and so continually flattened. The relation of this fact to the power of accommodation will be evident a little further on.

That part of the hyaloid membrane which immediately surrounds the lens is called the *capsule* of the lens, while that next to the capsule of the lens is spoken of as the *suspensory ligament*.

8.—*Ciliary Muscles and the Muscles of Accommodation.* There occur in the iris two sets of muscles; a circular set by the contraction of which the pupil is made smaller, and a radial set, the contraction of which causes an increase in the opening of the pupil. In addition to these muscles of the iris there are found imbedded in the choroid coat just at the point where the choroid coat and the cornea meet, a system of muscles known as the *muscles of accommodation*. These muscles are attached firmly at one end where the cornea and the choroid unite, from which point they extend backwards through the choroid in such a way that when they contract they pull the choroid coat forward towards the cornea. It will be pointed out that by means of these muscles the eye is focussed for far and near. At the point where the cornea and the iris meet there is a small canal running around the eye, called the *canal of Schlemm*. Between the two layers of the hyaloid membrane where they separate to enclose the lens there is a second canal encircling the lens called the *canal of Petit*. Between the suspensory ligament and the iris there is usually a small space which is but a continuation of the space containing the aqueous humor. This space is called the posterior chamber of the aqueous humor.

Reference to the diagram of the eyeball will show its close analogy to a camera, in which the refracting media are the cornea, the lens and the humors. The image will fall on the retina, and as the light usually enters the eye in a certain straight direction the image will regularly fall straight behind the lens. This point on the retina where the most acute vision occurs is called the *yellow spot*. It

is visible on the retina as a yellowish depression. When we wish to see objects in detail, such, for instance, as the print on a page, we allow the image to fall on this yellow spot. Images which fall on other portions of the retina are still visible but not distinctly so. At the spot where the optic nerve enters the eye the retina has no sensitiveness to light. This spot is called the *blind spot*. It may be easily found by trying the experiment suggested in Figure 170, in which the cross and circle are so arranged that when one falls on the yellow spot the other falls on the blind spot and so becomes invisible. The blind spot is sometimes called the optic mound, the yellow spot the macula lutea, while the pit in its center is called the fovea centralis. The retina at this point is so thin that the black choroid may be seen shining through it.

Fig. 170.—DIAGRAM TO DEMONSTRATE THE POSITION OF THE BLIND SPOT. (Close the left eye, and holding the figure about a distance of a foot from the face, look directly at the cross.)

At the optic mound a number of blood-vessels which reach the eye along with the optic nerve spread out through the retina and supply this coat with its proper nourishment.

9.—*The Optic Nerves.* In the chapter on nerves attention was called to the optic nerves; how these nerves met in the optic commissure and how the optic tracts passed from this point to the midbrain and occipital lobes. It was also pointed out that the crossing of the optic nerves at the commissure is only a partial one, and is of such a nature

that each side of the brain controls corresponding halves of the retina, so that the loss of the right optic tracts, for instance, would result in blindness of the left halves of both retinas. Of course if the optic nerve itself were cut then the entire retina to which it went would become blind.

10.—*The Microscopic Structure of the Retina.* In order to understand the physiology of the eye it is not absolutely necessary to go into the histological structure of very many of its parts. An exception to this, however, is the retina, which, as the seat of vision, has an exceedingly delicate structure, by means of which the light may be perceived. The microscope readily reveals ten distinct layers. These are, beginning with the one next to the hyaloid membrane, as follows:

First, a thin transparent membrane called the internal limiting membrane.

Second, a nerve fiber layer continuous with the optic nerve at one end and extending further into the retina at the other.

Third, the nerve cell layer, an ordinary ganglionic layer with which the nerves of the second layer probably connect.

Fourth, an inner molecular layer seen to consist of thin sections of very small granules, which granules, however, are probably systems of dendrons cut across. It seems probable that this molecular layer is a layer in which the dendrons of consecutive neurons meet. This is succeeded by,

Fifth, the inner nuclear layer, consisting of larger granules, which are undoubtedly small nerve cells, so that this layer may be looked upon as a second ganglionic layer. Next to this is found,

Sixth, the outer molecular layer, differing from the inner molecular layer only in being much narrower. This is succeeded by,

Seventh, the outer nuclear layer similar in construction to the inner nuclear layer and ganglionic in its function. The outer nuclear layer is bordered by a very thin membrane called,

Eighth, the external limiting membrane, followed by,

Ninth, the rod and cone layer, the layer in which the actual nervous stimuli arise. As the name indicates, two kinds of structures are found here, somewhat longer and narrower rods, and scattered between these shorter and thicker cones. These rods and cones project into,

Tenth, the pigment-cell layer, which lies in contact with the choroid just beneath.

Fig. 171.—DIAGRAMMATIC REPRESENTATION OF THE STRUCTURE OF THE RETINA. (After Y. Cajal.)

a, layer of rods *S* and cones *Z*; *F*, *F*, fibers of Müller; *h*, *h*, external limiting membrane; *b*, outer nuclear layer; *c*, outer molecular layer; *d*, inner nuclear layer; *e*, inner molecular layer; *f*, nerve cell layer; *g*, nerve fiber layer; *k*, *k*, internal limiting membrane. The rods are composed of a highly refractive end portion and a somewhat more protoplasmic basal portion which then, continued through the cells *K* in the layer *b*, end in the layer *c* in little round buttons. Several such buttons seem in turn invested by the dendrons of a single cell *H* from the layer *d*. The cones also have a refractive terminal portion, but a more rounded ellipsoid basal portion of protoplasmic structure, from which a relatively large fiber at once passes through the layer *b*, and ending in dendrons in the layer *c*, invests the dendrons of a single cell of the layer *d*. The layer *d* contains also cells *L*, which run outward only, and cells *M*, which send dendrons inward only. The superposition of neurons is quite evident, there being in the retina itself at least three such superposed units.

Here and there through the retina may be seen somewhat stronger fibers reaching from the internal limiting membrane as far as the rod and cone layer. They serve probably for purposes of support and are called the fibers of Müller. The meaning of the layers of the retina will be more evident by reference to Figure 171, which is a diagram-

matic representation of the relative arrangement of these layers. It will be seen that the retina consists of a number of neurons, the cell body of the first neuron being in the third layer. From these large cells nerve fibers extend in one direction along the optic nerve to the brain, but toward the fourth layer are given off short dendrons which meet with similar dendrons from the second neurons, the cells of which lie in the inner nuclear layer. These cells send their dendrons into the sixth layer to meet similar dendrons belonging to neurons whose cells lie in the outer nuclear layer.

These cells extend a nerve fiber into the rod and cone layer. In fact, the rods are merely special terminations of these nerves. The cones seem to be partly of a cellular nature themselves, which connect with the lower neurons in the outer molecular layer and end in the rod and cone layer in the characteristic points found on these cones.

To resume, then, the retina consists of three systems of neurons super-imposed one above the other, the individual neurons being exceedingly small, but, on the other hand, exceedingly numerous. This decrease in size and corresponding increase in numbers is necessitated by the delicacy which the retina must possess to be affected by light and so make possible the perception of two points of light very close to each other. The touch areas for light in the retina must be very much smaller indeed than the touch areas for the portions of the skin since we are able to see two points of light which are separated by a distance measurable only with difficulty.

A somewhat surprising arrangement of the retina at first sight consists in the relative position of the first and ninth layer. Naturally one would expect to see the rods and cones turned towards the light. In reality they are in the human eye, as in the eye of all vertebrates, turned away from the light and the light has to permeate the eight super-imposed layers before affecting the sensitive rods and cones. This inversion of the retina is easily understood

when the embryonic development of the eye is studied. Very early in such development the retina can be seen folded in such a way that what would naturally have been towards the light is turned away from the light. In the invertebrates the rods and cones turn towards the light, and eyes having such an arrangement are, therefore, usually referred to as invertebrate eyes.

THE EYE AS A PURELY PHYSICAL INSTRUMENT.

The ability of the eye to bend rays of light passing through its refracting media and to produce an image on or near the retina is a purely physical property. Such results would occur in an eye that had been removed from the body. A stimulation of the rods and cones, however, and the consequent production of nervous impulses, which, when reaching the brain are interpreted as color, are physiological processes and can be duplicated in no artificially constructed instrument. Before proceeding to the physiology of the eye it seems desirable to call attention to those arrangements and properties which it shares with all optical instruments, and to the defects which may arise in the eye in common with other optical instruments.

THE NORMAL OR EMMETROPIC EYE.

When the eyeball and its refracting media are so constructed that parallel rays of light shall meet in a focus on the retina when the eye is in a resting condition, it is called a normal or *emmetropic* eye. Rays of light are for practical purposes considered as parallel when they come from a point removed from the eye about twenty-five feet or more. An emmetropic eye, therefore, may be defined as one which in its natural resting position is in focus for distant objects. Many eyes do not conform to this requirement, but show in a greater or less degree one or more of the following optical defects:

1.—*Myopia, or Short Sight.* In a myopic or short-sighted eye the image falls in front of the retina, produced

by either one or both of the following causes: (*a*) The ball may be too long from before backwards, and in this way the retina too far behind the lens to receive the image. Or, (*b*) the lens may be too convex. It may converge the rays of light too much and so bring them to a focus sooner than ought to have been done. When myopia is the result of a long eyeball it is frequently a natural defect. When, however, it is due to too great a convexity of the lens it may be an acquired defect. An individual who has been in the habit of looking closely at things held very near the eye, has been obliged in doing so, to keep his lens strongly curved, and the continuation of such a state of things is liable to finally fix itself and so there arises short-sightedness, which necessitates that all objects be held close to the eye to be distinctly visible.

In such acquired myopia there has occurred really no inherent change in the lens, the change has been in the muscle itself, which, owing to its constant tension in looking closely, has finally become somewhat fixed in this position, and by this fixation of the muscle the lens remains, on account of its elasticity, in constant excessive convexity.

The remedy for short-sightedness is obvious. As the rays of light are bent too much a lens must be placed before the eye which shall disperse them to such an extent that the image shall be thrown on the retina. Concave spectacles are therefore demanded, the extent of the concavity depending upon the degree of myopia.

Fig. 172.—THE MYOPIC EYE AND ITS CORRECTION.

The tendency to acquire myopia when the eye is repeatedly subjected to a close strain shows the necessity devolving upon teacher and parent to prevent the habit of reading continuously with the book unnaturally close. It

is an element of optical hygiene to insist that persons with normal eyes to begin with shall hold objects, such as a printed page, at a reasonable distance from the eye.

2.—*Long Sight or Hypermetropia.* Hypermetropia occurs when the image in the eye would naturally fall behind the retina, or since this is actually impossible, the real state of things is the absence of a focus altogether, the rays of light falling on the retina in a circle before they have met in a point. The causes of this defect are two. (*a*) It may consist of a shortening of the eyeball from before backwards, so that the retina now is in front of its natural position. Or, (*b*) since the rays of light are not converged enough the lens may be too nearly flat. The remedy in this instance is equally obvious. The converging power of the eye must be increased, and so convex glasses are needed.

As the image of an object is pushed further and further back in the eye the closer the object itself is placed to the eye, and as in the far-sighted individual this shifting of the image, backwards exaggerates the difficulty, such persons have a clearer vision when the object is removed some distance, whence, of course, the name "far-sightedness."

Fig. 173.—THE HYPERMETROPIC EYE, AND ITS CORRECTION.

It is well to point out, though, that in many cases far-sighted children will develop a habit of holding the book too close to the eye and so leave the impression on the observer that they are near-sighted. Such a far-sighted child in looking at the page before him does not see it distinctly, and prompted by the desire to look more closely and misled by his usually correct experience that approach to an object increases the distinctness of its vision, he moves the

page closer to his eye. The increase in the intensity of the light temporarily increases the clearness, but the difficulty is soon exaggerated and so frequently a second attempt to see more clearly is made by moving the object still closer. Teachers especially should be on the lookout for such cases since the confounding of far-sight with near-sight might lead to undesirable results. Far-sightedness also very generally induces inflamed conditions of eyes and eyelids, and seems a predisposing cause in the production of stytes.

3.—*Astigmatism*. The distinctness of an object, as any one will readily understand who has handled lenses of any kind, depends upon an even curvature and density of the lens in question. If the surface of a lens be made uneven, a greater or less distortion of the image occurs. If, for instance, a drop of water is allowed to run across the front of a pair of spectacles, objects seen through them are at once distorted. The water in this case having about the same density as glass, acts really like a bit of extra glass put on the spectacles, and so the surface of it is made uneven. The spectacles under these circumstances are astigmatic.

Exaggerated cases of astigmatism are also observable on nearly all window panes, for seldom (except in the case of plate glass) is a window pane so even as not to distort the objects seen through it, while sometimes the distortion is so great as to transform a straight object seen through it into a series of zig-zags.

It is not necessary that a lens should have such exaggerated cases of unevenness to be astigmatic. It may, in fact, be quite smooth, but if the curvature in one direction differs from the curvature in another direction, a distortion or relative change of focus for the various parts of the lens will arise. Rays of light passing through the lens where it has a greater curvature will come to a focus sooner than rays of light passing through portions of a lens having a lesser curvature.

Applying this to the eye we find that it not infrequently occurs that a cornea possesses such irregularities of curvature, and astigmatism is the result. The presence of astigmatism can be readily detected by looking at a disk on which are placed the numerals arranged like those on the face of a clock. Astigmatic persons will see some of these numerals in focus, while others are indistinct and blurred. When the focus is changed to the blurred ones and these become distinct, the first become blurred. Or if one look at a system of concentric rings, such as given in Figure 174, astigmatic persons will perceive certain sectors in which the lines are blacker and more distinct, bordered by portions where they are blurred and indistinct.

Fig. 174.—FIGURES TO DEMONSTRATE THE EXISTENCE OF ASTIGMATISM.

To remedy astigmatism it is necessary to grind a special lens of such a form that it shall exactly counteract the indistinctness of the cornea, the lens being more rounded where the cornea is not rounded enough, and hollowed out where the cornea possesses too much curvature. The fitting of a lens for astigmatism must in each case be a bit of special work, there being possibly no two cases of astigmatism exactly alike.

4.—*Cataract.* Cataract is an optical defect arising from the opacity of the lens. When light is no longer able to penetrate this readily, a more or less complete blindness results, the only remedy for which is the removal of the lens from the eye and the substitution for it of an artificial lens in front of the eye.

In addition to the usual cataracts of the lens, there occur sometimes slight opacities in the cornea.

5.—*Spherical Aberration.* Spherical aberration is not so much a real defect of the eye as it is a somewhat universal defect of all lenses, and it is therefore in common with all lenses shared by the crystalline lens. All the rays of light passing through a lens do not meet at the same point, but the rays of light passing near the edge of the lens are brought to a focus sooner than those passing nearer the middle, and consequently when the edge of the lens is in focus the center is blurred, and vice versa. Instances of such spherical aberration are frequently noticeable on ordinary opera-glasses, where when objects seen through the middle of the lens are in focus the field around the edge of the lens seems blurred. There would be two ways to remedy this defect. One to cut the light out of the edge of the lens by placing a circular shutter over it. Such is, in fact, very usual in optical instruments, and photographers frequently interpolate a shutter having a small hole in it through which the light is able to reach the center of the lens only. A similar arrangement exists in the eye where the iris cuts off the entire outer portion of the crystalline lens and permits the light passing through the pupil to reach the center of the lens only.

A second way to remedy spherical aberration would be to increase somewhat the density of the middle of the lens, for as the rays of light passing through the edge of the lens are bent more an increase of the density of the middle of the lens would bend the rays passing through it more, and so the foci would coincide. Both of these plans are followed in the eye, the function of the iris having just been pointed out, and in addition to this the lens has a slightly greater density in the middle, the result of these two agencies being to reduce this defect in most eyes to an imperceptible minimum.

6.—*Chromatic Aberration.* A second almost universal defect of lenses is chromatic aberration. This defect arises from the unequal refraction which the different colors suffer while passing through a lens. It will be remembered that the

formation of a spectrum is the result of such an unequal bending, the red rays being bent least, the violet rays most. Evidently, therefore, since white light is composed of the seven fundamental colors, the violet rays being bent more than the red rays will come to a focus sooner, and in this way there will be produced a number of foci corresponding to the number of different colors, and objects will appear violet, greenish, or red, according as the violet, green, or red focus falls on the retina.

Fig. 175.—DIAGRAM TO ILLUSTRATE THE CHROMATIC ABERRATION OF THE EYE.

r, r' , red rays; v, v' , violet rays; V , violet focus; R , red focus; m, n , position of image with a red border; p, s , position of image with a violet border.

This chromatic aberration is most marked near the edge of a lens, and a peep through most opera-glasses shows this defect very plainly. While the center of the field is plain white, the edge of the field is tinted with some color due to chromatic aberration. This defect is reduced to an almost imperceptible minimum in the human eye by the exclusion of the light through the edge of the lens.

7.—*Muscae-Volitantes*. While the humors of the eye are practically quite transparent there occur not infrequently small opaque particles floating in them, the shadow of which is by the light entering the pupil thrown against the retina and there perceived as a more or less black object, which by the mind is projected out into space. These are the flying motes. These opaque particles are remnants of embryonic blood-vessels in the humor.

8.—*Presbyopia*. As the name indicates, this is a disease which arises usually in advancing age. The ability to focus

the eye depends upon the elasticity of the lens. But this elasticity becomes gradually reduced and in old age frequently disappears altogether. Such persons are unable to accommodate their eyes for far and near, a defect familiarly called old-sight.

To remedy this it is obvious that several pairs of lenses are required to adjust the eye to several distances. Such persons will not infrequently have one system of lenses for far objects, a second system for relatively near objects, the objects in a room, for instance, and a third system to be pressed into service in such acts of vision as the reading of a printed page.

THE MANIPULATION OF THE EYE AS AN OPTICAL INSTRUMENT.

Every optical instrument must have some arrangement by means of which it can be focussed. In the photograph camera this focussing consists in moving the lens forward or backward, or in changing the relative position of the sensitive plate behind the lens. The microscope is focussed by lifting the tube of the microscope or dropping it closer to the object on the stage. In the telescope the focus is produced by shifting the relative positions of the lenses. Evidently there must be in the eye some arrangement by means of which it, also, may be focussed.

That such is the case is the commonest experience of every-day life. We are conscious of a change in the eye when we turn our view from a distant object to one close by, and this change in the eye is independent of any movement of the eyeball. We may close one eye and then look at two points lying in the same direction so that there is no turning of the eyeball, and yet a change from the focus of one to the focus of the other is a clearly perceivable one. This change in the eye is called the accommodation of the eye, and the question arises, how this is brought about.

HOW DO WE FOCUS THE EYE?

It is at once out of the question to think this is brought about by a lengthening of the eyeball, like a camera, or the

shifting of the position of the retina, as in the telescope, and surely the lens cannot move from the position in which it is so firmly held by the suspensory ligament. The change of focus is produced by a change in the curvature of the lens. That this is true may be easily demonstrated by the following experiment: If with suitable apparatus one observe the images reflected out of the eye it is not at all difficult to notice three such. A very clear reflection from the front of the cornea, a second image reflected from the front of the lens, and a third image from the posterior surface of the lens. If these three surfaces remain in the same position the relative positions of the images will remain, but if one or more of these surfaces should change in any way, the relative position and sizes of these images would vary. If, now, a person from whose eyes such images are reflected be asked to focus his eye for a distant object, and the position of the images noted, and the person be then asked to change the focus to a near object, two of the images change. The image from the front of the cornea is unaffected, showing that the cornea has remained stationary. The image from the back margin of the lens changes just a little, in such a way as to show that this surface has become more convex. The greatest change occurs to the image reflected from the front of the lens. This moves much more rela-

Fig. 176.—THE REFLECTIONS OF TWO BRIGHT SQUARES FROM THE CORNEA, FRONT AND BACK OF LENS, *A* IN REST; *B* WHEN THE EYE IS ACCOMMODATED FOR A NEAR OBJECT. THE IMAGES *a*, *a*, FROM CORNEA DO NOT CHANGE, NOR DO THOSE *c*, *c*, FROM BACK OF LENS, BUT *b* IN FIGURE *B* IS MUCH SMALLER, SHOWING AN INCREASE IN THE CONVEXITY OF THE FRONT OF LENS.

tively and shows that the front of the lens has been pushed forward and become much more rounded. A clearer proof

of the change of form of lens in the accommodation of the eye cannot be desired.

This change also accords with what we know of the property of lenses. We know, for instance, that when an object is moved closer to a lens the image which the lens forms is pushed further back, and if this pushing back is not desired the rays of light must be bent more; that is, brought to a focus sooner, a result easily produced by increasing the convexity of the lens. The problem, therefore, narrows itself down to the explanation of the manner in which this change of lens is brought about. The first element of this explanation is found in the elasticity of the lens. It is a quite elastic structure made up of almost transparent cells, and is in its usual position continually unnaturally flattened. This is proved by seeing that when the lens is removed from the eye it at once becomes more nearly round than before. It is flattened in spite of its elasticity by the pull which the capsule of the hyaloid membrane exerts upon it, and this pull is brought about by the pressure of the vitreous humor which it exerts upon the hyaloid membrane around it. The lens is flattened out much like a foot-ball would be flattened out if it should be put under a person's coat and the individual should then distend his lungs with air. To make the analogy more complete we might imagine the foot-ball placed between the outer cloth of the coat and the lining, and the coat then buttoned up. If now the chest were expanded, as the vitreous humor expands the hyaloid membrane, the foot-ball would be materially flattened. Thus, to repeat, in the natural resting condition of the eye the lens is flattened, and if the eye be a normal one, therefore adjusted to far objects. An increase in the convexity of the lens is brought about by producing a slack in the capsule and suspensory ligament surrounding the lens. This slack is produced by the action of the ciliary muscles already described. These, it will be remembered, are muscles imbedded in the choroid coat, one end fixed to the point where the choroid coat is firmly

attached to the sclerotic coat, the other ending loosely in the choroid coat where this runs backward around the eye-ball. It is evident that when these ciliary muscles contract they will tend to pull the choroid coat forward; that is, towards the lens. As the hyaloid membrane lies immediately underneath the choroid coat it will be pulled forward along with the choroid coat and so thereby produce a slackening of the tension of the hyaloid membrane, where it encloses the lens. As soon as the slack is produced, the lens by its inherent elasticity becomes more rounded, and by its increased convexity the focus of the eye is changed for a new distance. To maintain this focus it is evident that the ciliary muscles must remain contracted and keep this slack, for as soon as the ciliary muscles relax the choroid coat and the hyaloid membrane with it move back to their original position under the pressure of the vitreous humor inside.

Fig. 177.—TO SHOW THE RELATIVE SHAPES OF LENS WHEN AT REST (LEFT HALF) AND WHEN ACCOMMODATED FOR NEAR OBJECTS (RIGHT HALF).

For explanation of other structures see the text.

To recur to the analogy above, let us imagine the football between the cloth and the lining of the coat. The coat represents, therefore, the hyaloid membrane. To represent the choroid coat around this hyaloid membrane imagine an overcoat put over the coat. It will be readily seen that if the overcoat could by means of the hands or any agency be pulled forwards towards the chest, it would tend to pull the

coat underneath it with it, and there would be produced in the coat a slack over the chest. The elastic foot-ball imbedded in the coat would at once take advantage of this slack and try to return to its natural round position. As soon as the forward pull on the sides of the overcoat ceased, the overcoat and the coat underneath it would fall back to their natural position under the regular pressure of the enclosed body. Accommodation is thus the product of two factors: first, the pulling forward of the choroid coat and with it the hyaloid membrane next to it, and the consequent production of a slack of the suspensory ligament and capsule. Second, the elasticity of the lens which enables it to take advantage of this slack to return, to some extent at least, to its more rounded form. Either the paralysis of the muscles or the loss of elasticity of the lens would at once make the accommodation of the eye impossible.

This explanation is the one advanced by Helmholtz, and is the one which is now almost universally accepted as correct. Recently there has been advanced, on not very good grounds, however, a second explanation. According to this second explanation the increase in the convexity of the lens is brought about by the contraction of some circular fibers which seem to lie among the radial fibers of the ciliary muscles, by the contraction of which circular fibers the lens is rounded. As these circular fibers are said to surround the lens like a rubber band, it is clear how a flattened object would have its convexity increased by a circular pressure exerted upon it in the manner indicated, but as most of the fibers of the ciliary muscles are radial fibers, and as even the few circular fibers do not lie sufficiently close to the margin of the lens, this explanation does not seem satisfactory, especially so in view of the completeness of the other explanation.

It will be remembered in the chapter on the distribution of nerves that the ciliary muscles are innervated with branches from the oculi motores.

With the process of accommodation are associated changes in the size of the pupil. The enlarging of the

pupil is accomplished by the radial fibers of the iris, its contraction by the circular ones. The pupil changes its caliber under the following circumstances:

First. Very strong light thrown into the eye causes a contraction of both pupils, even when the strong light is admitted to one eye only.

Second. Under a constant light the pupil contracts when the eye is accommodated for objects near by.

Third. A contraction of the pupil seems to accompany the movements of the eyes inwards. This is probably but a special case of number two, as ordinarily the eyes are turned inward when they are accommodated for near objects.

Fourth. The pupil is contracted in sleep.

Fifth. The pupil is much dilated in cases of asphyxiation. A dilation also usually follows a strong stimulation of any large region of the skin of the body.

Sixth. Various drugs have a decided effect upon the pupil. Thus, atropin and belladonna dilate the pupil, while nicotine and morphine cause it to contract.

THE DIOPTRICS OF THE EYE.

In a general way the passage of rays of light through the media of the eye has been pointed out, and while it would be out of place here to go into the detailed mathematical considerations of the various foci and indices of refraction a few elementary considerations of this nature seem appropriate. Although the eye consists of several refracting media, these three media may mathematically be resolved into one, and the cardinal points for such a composite medium be determined. In Figure 178 the line // actually indicates the curvature of a lens of the density of the vitreous humor which would have the same refracting power as the entire eye. To determine at what point on the retina the refracting media of the eye will throw an image it is necessary that several determining points of these media be established. These have, with considerable

accuracy, been made out on the human eye and are given approximately correct in Figure 178.

It will be noticed that in the lens itself not far from its posterior portion there are indicated two points marked k' and k'' . These are called the nodal points of the eye. A ray of light entering in any direction through the pupil and passing through point k' will proceed from k' to k'' , and at k'' be bent parallel to its direction of entrance. As, however, for practical purposes k' and k'' are very close together we may imagine them as one point, and that any ray of light which passes through k' will be continued to the retina without suffering any bending

Fig. 178.—SEMI-DIAGRAMMATIC SECTION OF THE EYE-BALL.

The explanation of lines and letters is given in the text.

To know, therefore, where on the retina a certain luminous point will be imaged, it is necessary to draw a straight

line from the luminous point in question through the nodal point of the eye to the retina. If the eye be a normal one and focussed properly all the other rays of light from this same luminous point will fall at the same point on the retina as the straight unbent one passing through the nodal point.

In Figure 178 two directions of light are indicated. One, $F' F''$ passes through the horizontal axis of the eye, and passing through the point $k' k''$ suffers no bending. The line $G' G''$ is a second direction of light passing through the point $k' k''$ and so is continued straight back to the retina.

The line of light $G' G''$ is the common path of light falling on the yellow spot. It is apparent, therefore, that the geometric axis of the eye is not the path which the light usually takes in entering it, but that the yellow spot is slightly above the axis, thus necessitating in ordinary vision a constant, although slight rotation of the eyeball upwards.

It may be pointed out once more that all the refracting media of the eye reduced to a single medium would in its optical action be that of a spherical surface of vitreous humor of a little over 5 mm. radius, as indicated by the line ll in the figure, which surface would have as its central point the nodal point indicated by the letter H'' .

THE LUMINOSITY OF EYES.

On account of the black choroid which lines the inside of the eye, very little light indeed is reflected back out of the eye, it being all absorbed by this coat. For this reason the pupil looks black. It is true, though, that even in the human eye a little light is reflected out of the pupil, enabling an observer by means of proper instruments to see the retina. In many of the lower animals, on the other hand, a very much increased amount of light is reflected through the pupil, sometimes to such an extent as to make the eyes luminous, as for instance, those of a dog, cat, or tiger. This is brought about by the presence of a reflecting membrane in the back of the eyes of these animals, called the

tapetum. This luminosity of the eyes is most readily observable if such an animal be placed in a darkened room and light admitted through a door in which the observer himself stands. In that case it is frequently possible to see the two eyes luminous enough to shine in the dark, the explanation being, as just pointed out, the light which is actually reflected out of the eye by the shining tapetum within.

THE PHYSIOLOGY OF COLOR SENSATION.

Up to this point the eye has been treated almost exclusively as a purely physical instrument, unless we except the nerves and muscles by means of which it accommodates itself. But all these physical arrangements in the eye are intended to make possible the physiological perception of color in the retina. It has been pointed out how the image is spread upon the retina, and there arises now the question how this physical image is translated into physiological phenomena. In other words, how do we see colors?

It is well to note that it is color and color alone that we observe with the eyes. Distance, solidity, form, size, etc., are all inferences which we draw from the arrangement of colors before us. The eye sees color or absence of color, and arrangement of colors, and nothing more.

The physiology of vision pure and simple, therefore, narrows itself down to the perception of these colors. Unfortunately we are yet far removed from a complete understanding of this question, and the theories that have been advanced have left so much still unexplained that they have scarcely the dignity of scientific theories. They are, however, the best attempts, in the light of what we now know, towards the explanation of these phenomena.

Two fairly distinct theories are proposed. These are the Young-Helmholtz theory, as suggested by Young early in this century, and later on materially modified by Helmholtz. It seems to offer the most plausible explanation and is the one probably most generally accepted. The other theory is that of Ewald Hering, which explains colors upon

an entirely different basis. Both theories, however, start from facts and observations which are afforded by instances of color blindness, and so before giving these theories it may be desirable to describe somewhat in detail the various kinds of color blindness observed. Two distinct kinds of color blindness are found called respectively monochromatic, and dichromatic color blindness. Of the dichromatic blindness two varieties occur called red blindness and green blindness. More correctly, however, the terms monochromatics and dichromatics are applied to the persons themselves showing these defects.

COLOR BLINDNESS.

Monochromatics. As the name indicates, these are persons who see but one color. This color seems to be a bluish white. Such monochromatics see the world, about as we do, as far as distinctness is concerned. They can recognize objects readily. The world appears to them about as it appears to us in a photograph or an etching. It will be remembered that in photographs and etchings but shades of white and dark, as a rule, are used. Yet so true may a photograph be, using only these two colors, that we fail to notice frequently the absence of the spectral tints. It is even possible for such monochromatics to live for some time without really suspecting their defect, attributing their lack of color perception frequently to stupidity in that direction rather than a real optical disability. Such monochromatics show when they are looking at objects a peculiar habit of squinting the eye, as if they were focussing with effort. They seem to have some difficulty to turn their point of acutest vision on the object in question. Strange as it may seem, such monochromatics may sometimes successfully recognize colors, but when they do so it is for the same reason that a photographer may recognize colors on his photograph, having learned by experience what the appearance of red or yellow in the photograph will be, and so these monochromatics having red pointed out

to them repeatedly they are sometimes enabled to recognize the red by a slightly different appearance which it shows to them in their single color.

Monochromatic color-blindness is not very general. Relatively few cases have been scientifically noted. The explanation of the phenomena of monochromatic eyes will be explained in terms of each theory further on.

Dichromatics. Dichromatic eyes see but two colors. These are blue and yellow. Of course black is not counted as a color in any of the eyes, black being simply the absence of light, and in this sense it would be correct to say that a totally blind individual could still see black. These dichromatic eyes see the blue about as we do, but instead of green, yellow and red, they see but yellow alone.

1.—*Green-Blindness.* Two distinct varieties of dichromatic eyes occur. The varieties are so marked off, that gradations from one into the other do not seem to exist. One variety of dichromatic eyes sees yellow where we see red, but sees no definite tint where we see green. Such persons are called green-blind. They seem to their friends to be perfectly able to recognize the red, but the red is to them really an intense yellow, which they have learned to call red because it has always been pointed out to them as red, while green they are not able to recognize except as a paler yellow, and this inability to readily pick out green objects has given them the name of green-blind persons.

2.—*Red-Blindness.* In the second variety of dichromatic eyes (a variety which is more numerous than either of the others) the yellow is seen most intense where we see green, while our red is to them a very indistinct color something like a pale yellow. They readily pick out green objects, because these appear to them a bright yellow, calling them green, however, for reasons explained above. Such persons not being able to clearly distinguish the red are called red-blind persons.

It is said that about one female in twenty-five is affected with color blindness of one variety or another, and about one male in every eight or ten. Red-blindness is the more frequent defect. It is hard to explain the relatively higher per cent. of color-blindness in men, unless it is due to the fact that they pay relatively less attention to colors and that this neglect in their visual education has contributed to this defect.

What we call green-blindness and red-blindness are, after all, varieties of the same defect, for red-blind and green-blind alike see blue and yellow only. In the green-blind people our red seems a most intense yellow, while in red-blind people our green seems most intense. As it is exceedingly necessary in many professions, especially that of navigation and railroading, that employes shall be able to readily distinguish between a green signal and a red danger signal, such corporations now very generally subject their employes to a very careful color test in order to preclude as much as possible an accident from such a lack of discrimination.

With a general description of these three varieties of color-blindness we are enabled to understand possibly a little more readily each of the two attempts made to explain them, as well as the color sensations of the normal eye.

THE YOUNG-HELMHOLTZ THEORY.

According to this theory there are found in the retina three kinds of nerve fibers, physiologically considered. To these three different kinds of fibers are attributed respectively sensations of *red*, *green* and *blue*. The sensation of blue is attributed to the *rods*. It will be remembered that the rods are scattered over the entire retina but are wanting in the yellow spot, for which reason, if this theory be true, the yellow spot should be blind to sensations of blue. And such seems really to be the case. If with proper apparatus one arranges a blue point in such a way that it shall fall right in the fovea centralis, it seems to disappear, while red

and green points persist. In the author's own experience such a disappearance of the blue when falling right in the fovea centralis seems unquestionable from repeated experiments. There is, however, a cause that might produce the disappearance of the blue point apart from the absence of the cones. It will be remembered that the fovea centralis lies in the yellow spot, and we know that yellow light very rapidly absorbs blue light. Blue light does not readily pass through a yellow window pane, and so the disappearance of a blue point on the retina may be due to the fact that the yellow pigment of the yellow spot absorbs the blue light and so prevents it from affecting the retina.

According to the Helmholtz theory, however, the blindness of the yellow spot with reference to blue is due to the absence of the rods. The rods being distributed over all other portions of the retina explains why blue is thus generally present. It will also be remembered that the *vision purple* found in the eye occurs only in the rods, and so this theory goes a point further suggesting that it is a chemical action of the vision purple produced by the light that irritates the rods and so occasions a nervous impulse leading to the perception of blue.

Monochromatic eyes are upon this theory explained as eyes in which the rods alone are functional. The yellow spot is then entirely blind, and to this blindness of the yellow spot is attributed the difficulty in focussing and the habitual squinting which marks monochromatic persons. The points of acute vision in these monochromatics not being a definite spot, but a circle around that spot, the attempt to keep the focus on this circle occasions their extra efforts in looking closely.

But even normal eyes are monochromatic at times. When the ordinary light of day is very much reduced, as it is some time after sunset, we notice how the sensation red disappears first, then green, while blue is the last sensation to go. Every one must have noticed that a night scene has a bluish cast. Pictures of night scenes are purposely tinted

blue. A moonlight scene in a picture is readily distinguished from a view by day in the absence of all reds, and the prevailing tint of blue. In subdued light red and green disappear, and things before they shade into blackness seem to pass through gradations of deeper and deeper blue. According to this theory we have lost the use of the cones and our vision is limited to the rods. Therefore, we, too, ought to be blind in the yellow spot, as this possesses no rods, and the holders of this theory in support of this, point out the difficulty we have in distinct vision even when the light would still be strong enough to permit the details to be seen carefully.

Dichromatic eyes are explained by supposing that in addition to the rods which see blue, there are cones which see yellow, and the two varieties of dichromatic eyes are explained by the relative ease with which these yellow cones are stimulated. In red-blind individuals they are stimulated most readily by green objects; in green-blind persons the yellow cones are stimulated most readily by red objects.

NORMAL OR TRICHROMATIC EYES.

In the normal eye this theory supposes, as was stated, three sensations: blue, green and red. A grievous fault of this theory is its inability to explain why the second color in dichromatic eyes should be yellow, and why this color should not be represented at all in the trichromatic eyes. One would naturally suspect that in normal eyes the addition would be made to the blue and yellow of partially color-blind eyes. It was, in fact, this difficulty to explain how the yellow of dichromatic eyes was replaced by green and red of the trichromatic eyes that led to the proposal of the Hering theory, which explains this point at least satisfactorily.

It will be noticed that a normal eye might be derived from the composition of a green-blind eye and a red-blind eye. Thus dichromatics see blue just as we do. This is

one color. The green-blind people see our red, although it is yellow to them. In other words, their sense of sight is aroused by what we call red. This is the second color.

Fig. 179.—DIAGRAMMATIC REPRESENTATION OF THE STRENGTHS OF THE THREE FUNDAMENTAL SENSATIONS IN THE DIFFERENT PARTS OF THE SPECTRUM.

1, curve for color red; 2, curve for green; 3, curve for blue. The red curve should show a small added elevation at the violet end, since the stronger reappearance of the red there causes with the blue the production of the violet.

In red-blind persons the sensation of yellow is produced by what we call green. Such a composition of two dichromatic eyes would therefore be (1) blue, (2) yellow where we see green, (3) and yellow where we see red. Now, it is just possible that for psychological reasons this primitive yellow sensation has been divided into two separate sensations which we have learned to call red and green. One can easily understand how by having two colors, even if they are somewhat alike, side by side before the eye, that it would tend to make distinctions which would otherwise go unnoticed.

The normal eye is usually spoken of as a trichromatic eye because of its ability to perceive three different sensations. By the varying compositions of these different sensations all the shades and tints, and intermediate colors may easily be derived. When all three fibers in the eye are stimulated in the proper proportion, white is the result. This may be shown to be true by taking a card on which the red, green and blue are put in the proper proportion and then whirling it rapidly. The three colors melt together and the sensation of white results. The red and the

blue produce purple. Red and white a sensation in which the red nerves are more stimulated than in the proportion of white, produces pink. Violet, although usually indicated in elementary books as one of the fundamental color sensations, is in reality not one, but is a mixture of the blue and red, for it will be remembered when the number of vibrations of the various colors was given that it was pointed out that the violet was just an octave above the red, and that the red seemed to appear again there mixed with the blue. It was pointed out in the case of sound that a string set in vibration by a certain sound would be readily affected by its octave. So a nerve in the retina that is affected by red seems also affected by an octave of red, and for that reason blue will gradually shade into the violet as the octave of the red is there approached. As the sensation of blue was attributed to the rods, yellow and green sensations and the colors into which they enter are attributed to the cones.

Fig. 180.—GRAPHIC REPRESENTATION OF THE COMPOSITION OF COLOR SENSATIONS IN TERMS OF THE YOUNG-HELMHOLTZ THEORY. THE CURVES FOR RED, GREEN AND BLUE ARE HERE SUPERIMPOSED.

THE HERING THEORY.

According to the theory of Hering there are in the retina three different *color substances* which are either in process of being made, assimilation, or in process of destruction, dissimilation. One of these color substances he calls his *white-black* substance. When this substance is being produced in the eye the sensation of black results; when it is being destroyed in the eye the sensation of white results. Hence, objects appear white when the light falling into the eye causes this white-black substance to disintegrate. Things appear black when on that point of the retina this white-black substance is being formed.

Hering explains monochromatic eyes as eyes that possess but this white-black substance. He questions the bluish tint which many monochromatics have and explains the appearance of the world as monochromatics see it as that of a black and white steel engraving. As this white-black substance is produced when no light enters the eye things seem black in the absence of light.

Dichromatics possess in addition to this white-black substance a *blue-yellow* substance. This substance when it is being destroyed in the eye produces blue; when it is being re-formed in the eye produces yellow sensations. Looking at a blue object according to this theory would produce a disintegration of this substance, which would occasion the sensation blue, while looking at a yellow object would cause the production of some of this substance and in this way the retina be affected to see yellow.

Finally, in normal eyes there is, in addition to the white-black substance and the blue-yellow substance, a *red-green* substance. Here, too, a disintegration of the same produces red, a production of it, green sensations. While this theory seems very fanciful at first, it explains the dichromatic eyes and further gives us a reason for many of the phenomena which may be observed in studying after-images and color contrasts.

AFTER-IMAGES.

An after-image is, as the name suggests, an image retained on the retina after the stimulus producing it has ended. Such after-images may be of two kinds: positive, when they have the same color as the object, or negative, when they have the complementary color.

1.—*Positive After-Images.* The forming and disappearance of an image on the retina is, from a physical standpoint, as instantaneous as the changes of light, but the sensation which this image produces will sometimes continue after the stimulus is gone. Thus, a sky rocket seems to leave a trail of fire after it; a red-hot coal swung

around on a string looks like a luminous circle; a point of light moving rapidly up and down looks like a luminous stick. All this is explained on the ground that the sensations linger and that we therefore see the rocket in a certain position after it has left it and attained a new one. We see a rapidly moving luminous object in the position in which it is at the moment, together with quite a number of positions through which it has just passed, and in that way its path becomes luminous. A rapidly rotating wheel shows none of the spokes distinctly for similar reasons. If, in a room lighted by a gas jet, the gas be suddenly turned off while one is looking at it, an image of the flame remains an instant or two after that on the retina. Possibly the most familiar illustration of this fact is in the lightning, a stroke of which seems to us to extend in a continuous although zig-zag line from the cloud to the earth.

Positive after-images retain not only the shape, but also the color of the object and offer no serious difficulty in their explanation. It is not so easy with negative after-images.

2.—*Negative After-Images.* If one glances at the sun just an instant and then looks up into the sky in a different direction one sees a round black disk, If one looks intently with the eyes fixed on a red light and then shifts his view to a white wall an image of the light looked at is projected against the wall but in different colors, usually bluish or greenish. Or, if one looks out of the window intently for some time, then turns the look to the wall, the white window panes are black, the black window frames somewhat light in the negative after-image. An after-image retains the form and size of the real image, but in its complementary colors. A very clear illustration of this on a wider scale is afforded by placing close before the eye an intensely red light and looking at the same for some time, even at the risk of tiring the eye. Upon turning now to a room lighted with electricity or gas light, or even ordinary day light, the objects possess an intensely bluish tint,

which only gradually fades and disappears. Here the entire retina having been stimulated with red, everything later pictured upon it is clothed with bluish tints the complementary color of red. We have now to consider how these negative after-images are accounted for by Young's theory and by Hering's.

EXPLANATION OF NEGATIVE AFTER-IMAGES.

These negative after-images are explained by the Young-Helmholtz theory as due to the fatigue of the retina. If one looks intently for some time at a red light evidently the red nerves of that part of the retina on which this image falls will be stimulated, while the green and the blue nerves are resting. If this stimulation continues it is evident that these red nerves will become fatigued. There will be a tendency for the red object to become paler and paler as this effect proceeds. If, now, the eye be turned upon a white wall the entire retina is flooded with white light. In that part of the retina where the red image was the red nerves are fatigued and so do not respond; at least not fully. The consequence is that the green and blue nerves react alone and so that area appears a greenish-blue or a bluish-green. As the red nerves gradually recover from their fatigue their stimulation is mixed with the blue and green, which of course produces white. This explains very satisfactorily the complementary color of the negative after-image and how it is gradually transformed back into white.

But not only may one nerve be thus fatigued; two or even three may be so affected. If one, for instance, gazes at the sun an instant the image of the sun falling on the retina and strongly stimulating that portion, fatigues it. When, now, the view is turned in another direction this portion of the retina which the sun's image had fatigued fails to be fully excited, and so there arises the sensation of black, or, if the excitation is only a partial one, shades of gray.

This theory also explains why looking from one color to a complementary one seems to increase the brightness of the second. An animal grazing in the field and seeing practically nothing all day except the green grass and the green foliage, has a much more vivid impression of a red object when this is suddenly presented, than it would otherwise have, the explanation being that the red nerves have been resting all day, and then suddenly stimulated they react with great energy. The offense which certain animals seem to take at such bright objects flared at them may be to a slight extent at least accounted for in this way. Every stroller through the woods must have been struck with the intense redness of a summer redbird or a cardinal as it darted in among the green leaves.

In terms of the Hering theory negative after-images are explained as follows:

Taking, for instance, the supposed red-green substance of the eye which when it is being destroyed produces red sensations, when it is being regenerated produces green, it seems entirely possible that the excessive destruction of it might induce its regeneration. Just like an active destruction of muscle tissue is the occasion for a corresponding active regeneration of it. An increased use of any product of the body very naturally brings about an increased production.

Turning now to the first illustration, it is supposed that while the eye is looking intently at a red object this red-green substance is in that part of the retina where the image falls being used up, and if the look continues, is being exhausted rapidly. If, now, the eye is turned away there is naturally induced an attempt of the eye to produce some new substance of this kind, and this regeneration acting as a stimulus gives us the sensation of green. So with the other two substances. If the white-black substance had at some point of the retina been almost exhausted by staring an instant at the sun, say, there would occur at that point in the retina as soon as the eye was turned away a regener-

ation of this substance, and so a sensation of black. It is unnecessary to carry this further with the yellow-blue substance.

If two substances were simultaneously being exhausted then there would be induced the regeneration of both, and in this way there would arise in the eye various intermediate colors corresponding to the intermediate colors first looked at. It is apparent that the negative after-image will be not far from the complementary color of the object looked at.

It will thus be seen that both theories account more or less satisfactorily for many of the phenomena of color sensation, and each reader will have to decide for himself the relative probability of these two views. A point, very much in favor apparently of the Young-Helmholtz theory lies in the fact that owls and bats, which from their habits would naturally be suspected of being monochromatics, possess rods only, the cones being entirely absent. A second point in its favor is the observation that we are not able to see red towards the periphery of the retina. For instance, if one take a red object, such as a stick of red sealing-wax, and move it from behind the head forwards it does not appear red at first, and must be moved some distance further even after its outline is recognizable, when suddenly the sensation red flashes into consciousness. Blue and green, however, are more readily recognized at the periphery. Now, in terms of the Hering theory it would be impossible to see green where one cannot see red, since one substance is the cause of both. The explanation that suggests itself is that green and blue nerves occur here only, the red ones being absent.

DOUBLE VISION.

So far everything that has been said would apply if we had but one eye, but, as a matter of fact, we use two eyes in looking at objects and the question naturally arises, why vision with two eyes should result in an apparently simple

visual sensation. Every normal individual when looking directly at an object sees it as one object. It is possible, however, to see objects double, of the truth of which one may easily satisfy himself by holding a pencil before his eyes and then looking past the pencil into the distance. He will perceive two pencils. Of course if he turns his focus upon the pencil before him the two pencils will melt into one and the object appear single. But in that case the objects in the distance appear more or less double. There are on the retinas *corresponding points*, the simultaneous stimulation of which produces in the mind but a single sensation, and we ordinarily see objects single because we turn to the object, corresponding points. If, on the other hand, the image of anything should fall on points which do not correspond, each image will produce its own sensation and so we see double.

To determine which are corresponding points of the retina it is only necessary to imagine the retina of one eye laid right over the retina of the other eye in such a way that the yellow spots would coincide as well as the meridians passing through the yellow spots. In that case the points lying immediately above and below each other are corresponding points. For a point in the upper and outer part of the retina of the right eye, the corresponding point of the left eye would be found in the upper inner portion. Reference to Figures 181 and 182 will help to clarify this. Thus, in Figure 181 the gaze is directed for the point f , which is seen as a single point because its images at c and c fall on corresponding points, but the point g is seen double at G and G^2 because the images of it fall on points g' and g^2 which do not correspond. The corresponding point to g' is of course g^3 . Turning now to the next figure in which the point G is seen single because its images at c and c fall on corresponding points, f is seen double at F' and F^2 , because the images of point f fall at f' and f'' , which are not corresponding points, the corresponding point to f' being f^3 .

From these figures it will be seen that only one point can be seen single at one time; all other points appear

Fig. 181.

Fig. 182.

Figs. 181 and 182.—DIAGRAMS TO SHOW THE ORIGIN OF DOUBLE VISION.

more or less distinctly double. We are not aware of the doubleness of these outside-lying points for the following reasons:

First. To see an object clearly we turn to it the yellow spots of both eyes, which are corresponding points. Hence all objects seen distinctly, that is, with the yellow spot, appear single.

Second. The other portions of the retina are not so sensitive as the yellow spot, and so the doubleness of the image does not press itself into the field of consciousness.

Third. Attention is usually riveted to those objects only which fall in or very close to the yellow spot, and we do not take cognizance of objects falling on the periphery of

the retina. A somewhat curious exception to this rule of double vision is found in viewing the starry heavens. Here all the stars appear as single stars, whether the image falls close to the yellow spot or on the periphery. This arises from the fact that owing to the immense distances of these objects the rays coming from them are practically parallel, and entering the eye in parallel lines all the images must naturally fall upon corresponding points. Reference to Figure 183, in which the rays of light from one star are given as lines 1 and 1, and rays from the second star given as lines 2 and 2, it will be seen that *c* and *c* and *a* and *a* are corresponding points.

Fig. 183.—DIAGRAM SHOWING THE COMPLETE CORRESPONDENCE OF RETINAL POINTS IN LOOKING AT VERY DISTANT OBJECTS, SUCH AS STARS.

THE ADVANTAGES OF TWO EYES.

Even if one eye were able to see all colors as perfectly as two, one or two decided advantages arise from the possession of two eyes.

First. The defect in the retina caused by the blind spot is remedied by the opposite eye, as the corresponding points

for the blind spot of one eye are very sensitive points of the other. In a similar way smaller pathological defects in the retina of one eye are more or less fully counteracted by the other.

Second. We are enabled to look at the same object from two different points of view, and so can see more of the object than with one eye alone. This vision from two different points gives rise to the *perception of solidity*. One may easily satisfy himself that notions of the solidity of objects are very materially dependent upon one's seeing them with both eyes. The stereoscope is based upon this principle. Two views are taken of the same scene from points some distance apart. These two figures are then mounted in such a way that one eye sees one photograph, the other eye the photograph from the other corresponding position. In this way there arises the sensation of solidity to such an extent that we actually seem to see certain portions of the picture projecting in front of the others. Of course the two views taken must not be from remotely removed points. In that case the mind is unable to blend the two pictures into one, and recognizes them as two distinct pictures.

When two entirely distinct scenes or objects are brought one to one eye and one to the other, the two eyes seem to strive for the mastery, and sometimes we see one picture, then suddenly the other. This contest of the two pictures is not really a process of the eye; possibly each eye sends the image of the picture before it to the brain, but the brain, unable to look at two different things at the same time, takes cognizance of one, then of the other, and so on. Such a result naturally occurs in persons who are cross-eyed. In such individuals the corresponding points of the retina are placed entirely awry, and each eye produces its own picture. Only one of these pictures rises into full consciousness, or, as we say, cross-eyed persons select one eye to look with. This frequently remains the same. Sometimes the attention is shifted to the other eye, which then becomes the seeing one.

Third. By determining the amount of motion necessary to move the view of the eyeballs from one point to another we make inferences as to the *distance* absolute and relative of the objects seen. If an individual closes one eye and then with his arm and finger extended forward, moves towards the wall with the intention of halting when his finger is, say just an inch from the wall, he will find himself quite unable to do this satisfactorily, sometimes touching the wall while he thinks he is still several inches away, at other times suspecting the distance from his finger tip to the wall to be about an inch, when it is five or six times that amount. His inability to form correct judgments of distance in this case arises from the lack of using both eyes.

OPTICAL ILLUSIONS.

It has been pointed out that the eye is enabled to give us sensations of color only. All knowledge of form, size, distance, solidity, etc., are inferences made by the mind. One would naturally suspect, therefore, that these inferences would occasionally prove faulty and so give rise to illusions, a deception which we then attribute to our physical senses instead of holding our own minds responsible for them.

Several of the more striking forms of illusions are mentioned here.

1.—*Irradiation.* A light area on a dark background seems larger than a black area on a black background, even when these areas are mathematically alike. A hole through an object, such as a wall, or even a piece of cardboard, seems larger than the solid piece that entirely fills the hole. A person in light attire seems larger than in dark attire. The explanation of this lies in the lack of sharp focussing in the eye. When the focus of an object does not fall directly on the retina, but the rays of light strike the retina before meeting at a point, it is evident that a larger area of the retina is affected. Turning to Figure 184 it is readily seen that the image of the point α is a correspond-

ing point on the retina $n n$ at c . If the focussing were not distinct and the rays of light should strike the retina as they

Fig. 184.—DIAGRAM TO SHOW THE EFFECTS OF IMPERFECT FOCUSING IN PRODUCING THE PHENOMENA OF IRRADIATION.

At either m, m , or l, l , there is a circular field of light instead of a point as at n, n .

do at $m m$ or at $l l$, a much larger portion of the retina would be covered. The image instead of being a point would be a disk. This disk covering a larger portion of the retina than it would do if it were exactly focussed, produces a sensation which is interpreted as much larger in extent. Thus, also, a black area in a light background would seem larger than it naturally is, because now the black area would not be sharply focussed, would spread over more retina and give rise to a sensation of larger extent. For this reason a person in dark attire would seem larger when projected against a white background just as a person in light attire seems larger when projected against the usual dark background.

2.—*Parallelism*. While we are usually able to distinguish with considerable accuracy the parallelism of two lines, there arises a deception when these lines are crossed with diagonal lines, as indicated in Figure 185, where the long lines are parallel, but seem not to be.

3.—*Distance*. We judge distance in several ways; by the size which the object appears to us to have when its actual size is known; by the distinctness with which we see it, and by the number of objects which lie between us and it. Unbroken distances are as a rule entirely under-judged. This is due to the fact that distances in which many objects are found seem longer than distances in which no objects

occur. For this reason ten miles on a level prairie with a clear view seem much shorter than when the intervening

Fig. 185.—OPTICAL ILLUSION. THE PARALLELISM OF THE LONG LINES IS DESTROYED BY THE CROSS-LINES.

space is filled with a multitude of striking objects. So in Figure 186 the distance from *a* to *b* seems longer than the distance from *b* to *c*. For a similar reason the first square in Figure 187 seems higher and narrower than the second. In Figure 188 the distance from *a* to *b* seems greater than the distance from *c* to *d*.

Fig. 186.

Fig. 187.

Figs. 186 and 187.—OPTICAL ILLUSIONS.

4.—*Size*. Primarily, the size of an object depends upon the size of its image in the eye, but we have learned by experience that the size of this image will depend upon the distance of the object. Therefore, when we know the distance we infer the size. It is the opposite, in short, of the inference of distance. When we are ignorant of the distance we are unable to judge size closely, our inferences being then based wholly upon the clearness with which it

can be seen and a comparison with objects lying near it. These inferences are frequently deceptive. A mountain which on account of its immense size stands out so clearly seems for that reason to be very close, and many a deceived tourist has walked miles to find that his mountain remained about as far away as ever. A person unaccustomed to the sea seems helpless in judging distance, and therefore size, and the guesses made by a group of passengers on board of an ocean steamer as to the distance and size of a certain vessel on the horizon will sometimes vary from one mile to twenty-five in the matter of distance, and from a small fishing smack to an ocean steamer in size.

Fig. 188.—OPTICAL ILLUSION OF LENGTH.

A rather interesting deception occurs in connection with the moon. The moon seems larger near the horizon than near its zenith. Very frequently the comparison is made as between a wagon wheel at the horizon and a cheese-box at the zenith. This apparent change in the size of the moon arises for two reasons. First, we imagine the moon to be farther away when near the horizon than when directly overhead. The globe of the heavens seems to us in fact, a flattened inverted bowl. The moon, however, having the same size at the horizon but being judged by us farther away, we think it larger. It is like the boy in the fable who projected a spider hanging from his hat rim against the distant heavens, and imagined it therefore a spectre reaching from the earth to the skies. The spider appeared no larger than it really was, but under the belief that it

was miles away it seemed to reach into the clouds. A second reason for the increased size of the moon lies in the comparison which we make of the size of the same with the objects in its range. We see for instance the moon about twice as wide as a certain chimney, the dimensions of which we know, and in an unconscious way we make calculations as to the moon's size. When the moon is overhead there are no intervening objects and the comparison does not occur.

5.—*Shine or Brilliancy.* It was pointed out in the discussion of the reflection of light that a perfectly smooth surface reflected the light in an unbroken way and would appear even to a single eye polished or shiny. But the sensation of the shine or brilliancy of a surface is very much increased when we look at it with both eyes. This seems to be due to the fact that the same amount of light is not reflected into both eyes. It is apparent that the reflection from a shining surface is not the same for different directions. Especially is this true if that surface should move slightly as, for instance, a surface of water. This slight disagreement between the sensations of brightness in the two eyes is interpreted by the mind as increased shine or brilliancy. It is possible experimentally to take two surfaces, neither of which when seen alone appearing polished, and, placing one before each eye and then illuminating them with different intensities, to produce a sensation of shine or brilliancy. The mind seems to combine the non-agreement of intensity of light reported by the two eyes into a new sensation. In this way arises, for instance, the brilliancy of reflected moonbeams from a rippling surface of water.

6.—*Entopic Illusions.* These are illusions which arise from a cause lying within the eye itself. They are:

(a) *Musæ volitantes.* These are commonly called the flying moths, and appear as little black spots which we project into space. These black spots are due to shadows which

small opaque bodies in the vitreous humor throw against the retina, which shadows we by mistake project outside of the eye. These opaque bodies in the vitreous humor are remnants of embryonic blood-vessels.

(b) *The figures of Purkinje.* These are figures produced by the shadows which the blood-vessels of the retina throw against the retina. The blood-vessels lie in the outer coats of the retina, and so whenever light enters the eye they cast a shadow on the deeper sensitive layers. Ordinarily we do not notice this shadow because we have been accustomed to it, as the shadows always fall on the same points of the retina, the light entering always at the pupil. In the same way we might become insensible to an object resting on a certain portion of the skin if it should remain there for any great length of time. When, however, the object is suddenly placed on a new bit of skin it produces a distinct sensation, so when the shadows of these blood-vessels fall on a new part of the retina we at once distinctly see them, and as usual project these shadows out into space. If an individual go into a room lighted only with a lamp and then move the lamp at one side of his head in such a way that the light of the lamp pass through the white portion of the eye on that side instead of through the pupil, he will suddenly see, especially if he look against a white wall, a branched system of vessels, and if the experiment is very successful may even note the translation of the individual corpuscles through these blood-vessels. The explanation is apparent. The light entering through the sclerotic portion of the eye causes the blood-vessels to cast a shadow in a different direction than when the light normally enters the pupil, and this shadow falling upon a new portion produces a sensation. These Purkinje figures may be produced upon suddenly emerging into the light after having been confined for some time in a dark space, or after a night's sleep upon suddenly opening the eyes. In this case the retina where the shadow normally falls has been resting

during the night and becomes sensitive when the shadow is suddenly projected against it.

From this long chapter on the eye it will be noted that while our knowledge is very satisfactory in certain directions there is much that needs further study and investigation. We understand the eye fairly well as a physical instrument, but the gap in our knowledge is in the physiology of the retina. Unfortunately it must be granted that neither the Young-Helmholtz theory nor the Hering theory explain satisfactorily all the phenomena. In conclusion there may be mentioned some observations made upon the eyes of birds which may lead in the future to important results.

There occur in the rods and cones of the retina of birds small, fatty globules, some of which are red, others yellow, and still others colorless. These globules are so situated that the light must pass through them before reaching the sensitive endings of the rods and cones in question. One can hardly resist the suggestion that these colored globules of fat determine to some extent, if not wholly, the sensation which the rod in which it is imbedded shall give. It is evident that the red globule, for instance, will absorb all the other colors and permit only the red to pass through, and so stimulate the end of the rod or cone. Similarly the yellow globules will permit only yellow light to pass through. One feels tempted to believe that there may be globules answering to the entire scale of simple colors and thus the retina become a veritable color sounding-box, its physiology somewhat analagous to the basilar membrane of the ear, with its strings attuned to the various vibrations. The many individual rods and cones might each be provided with some contained colored globule to permit only that light in question to pass through it and affect the retina. In fact, it would be as if each rod and cone had a little colored plate of glass spread before it which permitted only the light of that color to penetrate it, and consequently to stimulate it to a sensation. May it not be possible that in

the human retina there are such colors which we are, however, not able to see because these small globules might so blend their light as to appear white, just as the individual colors of the spectrum blend into ordinary white? This, however, takes us into the domain of guessing, a procedure which is not always scientific.

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