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2 POPULAR LECTURES

ON

SCIENTIFIC SUBJECTS

BY

HERMANN VON HELMHOLTZ

TRANSLATED BY

E. ATKINSON, PH.D., F.C.S.

FORMERLY PROFESSOR OF EXPERIMENTAL SCIENCE, STAFF COLLEGE

FIRST SERIES

WITH AN INTRODUCTION by PROFESSOR TYNDALL

New Edition

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TRANSLATOR'S PREFACE

TO NEW EDITION.

IN 1891 the seventieth birthday of Hermann von Helmholtz, and the forty-ninth anniversary of his taking the degree of Doctor of Medicine, was celebrated in Berlin in a manner which, whether for its universality or importance, has, perhaps, never fallen to the lot of a Man of Science during his lifetime.

The demand for a new edition of the translation of the two volumes of Von Helmholtz's Popular Scientific Lectures suggests that this is an appropriate occasion for a re-issue under conditions which make them accessible to a larger circle of readers.

The present edition is identical with the preceding ones; discussing as they do, with the hand of a master, fundamental scientific problems, these Lectures are not likely to be soon out of date.

To the second volume has been added a remarkable autobiographical account of the Author's scientific career and development, which formed the subject of an address given by Von Helmholtz in reply to the addresses of congratulation on the occasion of his Jubilee. This is taken, by kind permission of the publisher, M. Hirschwald, from a collection of the addresses and speeches delivered on that occasion.

E. ATKINSON.

March 1893.

425182

TRANSLATOR'S PREFACE.

IN bringing this Translation of Helmholtz's Popular Scientific Lectures before the public, I have to thank Mr. A. J. Ellis for having placed at the disposal of the Publishers the translation of the third Lecture; and also Dr. Francis, the Editor of the 'Philosophical Magazine,' for giving me permission to use the translation of the fifth Lecture, which originally appeared in that Journal.

In addition to the Editorial charge of the book, my own task has been limited to the translation of two of the Lectures. I should have hesitated to undertake the work, had I not from the outset been able to rely upon the aid of several gentlemen whose names are appended to the Contents. One advantage gained from this division of labour is, that the publication of the work has been accelerated; but a far more important benefit has been secured to it, in the co-operation of translators who have brought to the execution of their task special knowledge of their respective subjects.

E. ATKINSON.

AUTHOR'S PREFACE.

IN COMPLIANCE with many requests, I beg to offer to the public a series of popular Lectures which I have delivered on various occasions. They are designed for readers who, without being professionally occupied with the study of Natural Science, are yet interested in the scientific results of such studies. The difficulty, felt so strongly in printed scientific lectures, namely, that the reader cannot see the experiments, has in the present case been materially lessened by the numerous illustrations which the publishers have liberally furnished.

The first and second Lectures have already appeared in print; the first in a university programme, which, however, was not published. The second appeared in the 'Kieler Monatsschrift' for May, 1853, but, owing to the restricted circulation of that journal, became but little known; both have, accordingly, been reprinted. The third and fourth Lectures have not previously appeared.

These Lectures, called forth as they have been by incidental occasions, have not, of course, been composed in accordance with a rigidly uniform plan. Each of them has been kept perfectly independent of the others. Hence

some amount of repetition has been unavoidable, and the first four may perhaps seem somewhat confusedly thrown together. If I may claim that they have any leading thought, it would be that I have endeavoured to illustrate the essence and the import of Natural laws, and their relation to the mental activity of man. This seems to me the chief interest and the chief need in Lectures before a public whose education has been mainly literary.

I have but little to remark with reference to individual Lectures. The set of Lectures which treat of the Theory of Vision have been already published in the 'Preussische Jahrbücher,' and have acquired, therefore, more of the character of Review articles. As it was possible in this second reprint to render many points clearer by illustrations, I have introduced a number of woodcuts, and inserted in the text the necessary explanations. A few other small alterations have originated in my having availed myself of the results of new series of experiments.

The fifth Lecture, on the Interaction of Natural Forces, originally published sixteen years ago, could not be left entirely unaltered in this reprint. Yet the alterations have been as slight as possible, and have merely been such as have become necessary by new experimental facts, which partly confirm the statements originally made, and partly modify them.

The seventh Lecture, on the Conservation of Force, developes still further a portion of the fifth. Its main object is to elucidate the cardinal physical ideas of work, and of its unalterability. The applications and conse-

quences of the law of the Conservation of Force are comparatively more easy to grasp. They have in recent times been treated by several persons in a vivid and interesting manner, so that it seemed unnecessary to publish the corresponding part of the cycle of lectures which I delivered on this subject; the more so as some of the more important subjects to be discussed will, perhaps in the immediate future, be capable of more definite treatment than is at present possible.

On the other hand, I have invariably found that the fundamental ideas of this subject always appear difficult of comprehension not only to those who have not passed through the school of mathematical mechanics; but even to those who attack the subject with diligence and intelligence, and who possess a tolerable acquaintance with natural science. It is not to be denied that these ideas are abstractions of a quite peculiar kind. Even such a mind as that of Kant found difficulty in comprehending them; as is shown by his controversy with Leibnitz. Hence I thought it worth while to furnish in a popular form an explanation of these ideas, by referring them to many of the better known mechanical and physical examples; and therefore I have only for the present given the first Lecture of that series which is devoted to this object.

The last Lecture was the opening address for the 'Naturforscher-Versammlung,' in Innsbrück. It was not delivered from a complete manuscript, but from brief notes, and was not written out until a year after. The present form has, therefore, no claim to be considered an

accurate reproduction of that address. I have added it to the present collection, for in it I have treated briefly what is more fully discussed in the other articles. Its title to the place which it occupies lies in the fact that it attempts to bring the views enunciated in the preceding Lectures into a more complete and more comprehensive whole.

In conclusion, I hope that these Lectures may meet with that forbearance which lectures always require when they are not heard, but are read in print.

THE AUTHOR.

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INTRODUCTION.

IN the year 1850, when I was a student in the University of Marburg, it was my privilege to translate for the 'Philosophical Magazine' the celebrated memoirs of Clausius, then just published, on the Moving Force of Heat.

In 1851, through the liberal courtesy of the late Professor Magnus, I was enabled to pursue my scientific labours in his laboratory in Berlin. One evening during my residence there my friend Dr. Du Bois-Raymond put a pamphlet into my hands, remarking that it was 'the production of the first head in Europe since the death of Jacobi,' and that it ought to be translated into English. Soon after my return to England I translated the essay and published it in the 'Scientific Memoirs,' then brought out under the joint-editorship of Huxley, Henfrey, Francis, and myself.

This essay, which was communicated in 1847 to the Physical Society of Berlin, has become sufficiently famous since. It was entitled 'Die Erhaltung der Kraft,' and its author was Helmholtz, originally Military Physician in the Prussian service, afterwards Professor of Physiology in the Universities of Königsberg and Heidelberg, and now Professor of Physics in the University of Berlin.

Brought thus face to face with the great generalisation of the Conservation of Energy, I sought, to the best of my ability, to master it by independent thought in all its physical details. I could not forget my indebtedness to Helmholtz and Clausius,

or fail to see the probable influence of their writings on the science of the coming time. For many years, therefore, it was my habit to place every physical paper published by these eminent men within the reach of purely English readers.

The translation of the lecture on the 'Wechselwirkung der Naturkräfte,' printed in the following series, had this origin. It appears here with the latest emendations of the author introduced by Dr. Atkinson.

The evident aim of these Lectures is to give to those 'whose education has been mainly literary,' an intelligent interest in the researches of science. Even among such persons the reputation of Helmholtz is so great as to render it almost superfluous for me to say that the intellectual nutriment here offered is of the very first quality.

Soon after the publication of the 'Tonempfindungen' by Helmholtz, I endeavoured to interest the Messrs. Longman in the work, urging that the publication of a translation of it would be an honour to their house. They went carefully into the question of expense, took sage counsel regarding the probable sale, and came reluctantly to the conclusion that it would not be remunerative.¹ I then recommended the translation of these 'Populäre Vorträge,' and to this the eminent publishers immediately agreed.

Hence the present volume, brought out under the editorship of Dr. Atkinson, of the Staff College, Sandhurst. The names of the translators are, I think, a guarantee that their work will be worthy of their original.

JOHN TYNDALL.

ROYAL INSTITUTION:

March 1873.

¹ Since the date of the foregoing letter from Professor Tyndall, Messrs. Longman & Co. have made arrangements for the translation of Helmholtz's *Tonempfindungen*, by Mr. Alexander J. Ellis, F.R.S. &c.

ON THE
RELATION OF NATURAL SCIENCE¹
TO GENERAL SCIENCE.

Academical Discourse delivered at Heidelberg, November 22, 1862,

BY DR. H. HELMHOLTZ, SOMETIME PRORECTOR.

TO-DAY we are met, according to annual custom, in grateful commemoration of an enlightened sovereign of this kingdom, Charles Frederick, who, in an age when the ancient fabric of European society seemed tottering to its fall, strove, with lofty purpose and untiring zeal, to promote the welfare of his subjects, and, above all, their moral and intellectual development. Rightly did he judge that by no means could he more effectually realise this beneficent intention than by the revival and the encouragement of this University. Speaking, as I do, on such an occasion, at once in the name and in the presence of the whole University, I have thought it well to try and take, as far

¹ The German word *Naturwissenschaft* has no exact equivalent in modern English, including, as it does, both the Physical and the Natural Sciences. Curiously enough, in the original charter of the Royal Society, the phrase *Natural Knowledge* covers the same ground, but is there used in opposition to supernatural knowledge. (Note in Buckle's *Civilisation*, vol. ii. p. 341.)—
TR.

as is permitted by the narrow standpoint of a single student, a general view of the connection of the several sciences, and of their study.

It may, indeed, be thought that, at the present day, those relations between the different sciences which have led us to combine them under the name *Universitas Litterarum*, have become looser than ever. We see scholars and scientific men absorbed in specialities of such vast extent, that the most universal genius cannot hope to master more than a small section of our present range of knowledge. For instance, the philologists of the last three centuries found ample occupation in the study of Greek and Latin; at best they added to it the knowledge of two or three European languages, acquired for practical purposes. But now comparative philology aims at nothing less than an acquaintance with all the languages of all branches of the human family, in order to deduce from them the laws by which language itself has been formed, and to this gigantic task it has already applied itself with superhuman industry. Even classical philology is no longer restricted to the study of those works which, by their artistic perfection and precision of thought, or because of the importance of their contents, have become models of prose and poetry to all ages. On the contrary, we have learnt that every lost fragment of an ancient author, every gloss of a pedantic grammarian, every allusion of a Byzantine court-poet, every broken tombstone found in the wilds of Hungary or Spain or Africa, may contribute a fresh fact, or fresh evidence, and thus serve to increase our knowledge of the past. And so another group of scholars are busy with the vast scheme of collecting and cataloguing, for the use of their successors, every available relic of classical antiquity. Add to this, in history, the study of original documents, the critical examination of parchments and papers accumulated in the archives of states and of towns; the combination of details scattered up and down in memoirs, in correspondence, and in biographies; the deciphering of hieroglyphics and cuneiform inscriptions; in natural history the more and more comprehensive classification of minerals, plants, and animals, as well living as

extinct; and there opens out before us an expanse of knowledge the contemplation of which may well bewilder us. In all these sciences the range of investigation widens as fast as the means of observation improve. The zoologists of past times were content to have described the teeth, the hair, the feet, and other external characteristics of an animal. The anatomist, on the other hand, confined himself to human anatomy, so far as he could make it out by the help of the knife, the saw, and the scalpel, with the occasional aid of injections of the vessels. Human anatomy then passed for an unusually extensive and difficult study. Now we are no longer satisfied with the comparatively rough science which bore the name of human anatomy, and which, though without reason, was thought to be almost exhausted. We have added to it comparative anatomy—that is, the anatomy of all animals—and microscopic anatomy, both of them sciences of infinitely wider range, which now absorb the interest of students.

The four elements of the ancients and of mediæval alchemy have been increased to sixty-four, the last four of which are due to a method invented in our own University, which promises still further discoveries.¹ But not merely is the number of the elements far greater, the methods of producing complicated combinations of them have been so vastly improved, that what is called organic chemistry, which embraces only compounds of carbon with oxygen, hydrogen, nitrogen, and a few other elements, has already taken rank as an independent science.

‘As the stars of heaven for multitude’ was in ancient times the natural expression for a number beyond our comprehension, Pliny even thinks it almost presumption (‘rem etiam Deo improbam’) on the part of Hipparchus to have undertaken to count the stars and to determine their relative positions. And yet none of the catalogues up to the seventeenth century, constructed without the aid of telescopes, give more than from

¹ That is the method of spectrum analysis, due to Bunsen and Kirchoff, both of Heidelberg. The elements alluded to are cæsium, rubidium, thallium, and iridium.

1,000 to 1,500 stars of magnitudes from the first to the fifth. At present several observatories are engaged in continuing these catalogues down to stars of the tenth magnitude; so that upwards of 200,000 fixed stars are to be catalogued and their places accurately determined. The immediate result of these observations has been the discovery of a great number of new planets; so that, instead of the six known in 1781, there are now seventy-five.¹

The contemplation of this astounding activity in all branches of science may well make us stand aghast at the audacity of man, and exclaim with the Chorus in the 'Antigone': 'Who can survey the whole field of knowledge? Who can grasp the clues, and then thread the labyrinth?' One obvious consequence of this vast extension of the limits of science is, that every student is forced to choose a narrower and narrower field for his own studies, and can only keep up an imperfect acquaintance even with allied fields of research. It almost raises a smile to hear that in the seventeenth century Kepler was invited to Gratz as professor of mathematics and moral philosophy: and that at Leyden, in the beginning of the eighteenth, Boerhave occupied at the same time the chairs of botany, chemistry, and clinical medicine, and therefore practically that of pharmacy as well. At present we require at least four professors, or, in an university with its full complement of teachers, seven or eight, to represent all these branches of science. And the same is true of other faculties.

One of my strongest motives for discussing to-day the connection of the different sciences is that I am myself a student of natural philosophy; and that it has been made of late a reproach against natural philosophy that it has struck out a path of its own, and has separated itself more and more widely from the other sciences which are united by common philological and historical studies. This opposition has, in fact, been long apparent, and seems to me to have grown up mainly under the influence of the Hegelian philosophy, or, at any rate, to have

¹ At the end of November 1864, the 82nd of the small planets, Alcmene, was discovered. There are now 109.

been brought out into more distinct relief by that philosophy. Certainly, at the end of the last century, when the Kantian philosophy reigned supreme, such a schism had never been proclaimed; on the contrary, Kant's philosophy rested on exactly the same ground as the physical sciences, as is evident from his own scientific works, especially from his 'Cosmogony,' based upon Newton's Law of Gravitation, which afterwards, under the name of Laplace's Nebular Hypothesis, came to be universally recognised. The sole object of Kant's 'Critical Philosophy' was to test the sources and the authority of our knowledge, and to fix a definite scope and standard for the researches of philosophy, as compared with other sciences. According to his teaching, a principle discovered *a priori* by pure thought was a rule applicable to the method of pure thought, and nothing further; it could contain no real, positive knowledge. The 'Philosophy of Identity'¹ was bolder. It started with the hypothesis that not only spiritual phenomena, but even the actual world—nature, that is, and man—were the result of an act of thought on the part of a creative mind, similar, it was supposed, in kind to the human mind. On this hypothesis it seemed competent for the human mind, even without the guidance of external experience, to think over again the thoughts of the Creator, and to rediscover them by its own inner activity. Such was the view with which the 'Philosophy of Identity' set to work to construct *a priori* the results of other sciences. The process might be more or less successful in matters of theology, law, politics, language, art, history, in short, in all sciences the subject-matter of which really grows out of our moral nature, and which are therefore properly classed together under the name of moral sciences. The state, the church, art and language, exist in order to satisfy certain moral needs of man. Accordingly, whatever obstacles nature, or chance, or the rivalry of other men may interpose, the efforts of the human mind to satisfy its needs, being systematically directed to one end, must eventually triumph over all such fortuitous

¹ So called because it proclaimed the identity not only of subject and object, but of contradictories, such as existence and non-existence.—THE

hindrances. Under these circumstances, it would not be a downright impossibility for a philosopher, starting from an exact knowledge of the mind, to predict the general course of human development under the above-named conditions, especially if he has before his eyes a basis of observed facts, on which to build his abstractions. Moreover, Hegel was materially assisted, in his attempt to solve this problem, by the profound and philosophical views on historical and scientific subjects with which the writings of his immediate predecessors, both poets and philosophers, abound. He had, for the most part, only to collect and combine them, in order to produce a system calculated to impress people by a number of acute and original observations. He thus succeeded in gaining the enthusiastic approval of most of the educated men of his time, and in raising extravagantly sanguine hopes of solving the deepest enigma of human life; all the more sanguine doubtless, as the connection of his system was disguised under a strangely abstract phraseology, and was perhaps really understood by but few of his worshippers.

But even granting that Hegel was more or less successful in constructing, *a priori*, the leading results of the moral sciences, still it was no proof of the correctness of the hypothesis of Identity, with which he started. The facts of nature would have been the crucial test. That in the moral sciences traces of the activity of the human intellect and of the several stages of its development should present themselves, was a matter of course; but surely, if nature really reflected the result of the thought of a creative mind, the system ought, without difficulty, to find a place for her comparatively simple phenomena and processes. It was at this point that Hegel's philosophy, we venture to say, utterly broke down. His system of nature seemed, at least to natural philosophers, absolutely crazy. Of all the distinguished scientific men who were his contemporaries, not one was found to stand up for his ideas. Accordingly, Hegel himself, convinced of the importance of winning for his philosophy in the field of physical science that recognition which had been so freely accorded to it elsewhere, launched out, with unusual vehemence and acrimony, against

the natural philosophers, and especially against Sir Isaac Newton, as the first and greatest representative of physical investigation. The philosophers accused the scientific men of narrowness; the scientific men retorted that the philosophers were crazy. And so it came about that men of science began to lay some stress on the banishment of all philosophic influences from their work; while some of them, including men of the greatest acuteness, went so far as to condemn philosophy altogether, not merely as useless, but as mischievous dreaming. Thus, it must be confessed, not only were the illegitimate pretensions of the Hegelian system to subordinate to itself all other studies rejected, but no regard was paid to the rightful claims of philosophy, that is, the criticism of the sources of cognition, and the definition of the functions of the intellect.

In the moral sciences the course of things was different, though it ultimately led to almost the same result. In all branches of those studies, in theology, politics, jurisprudence, æsthetics, philology, there started up enthusiastic Hegelians, who tried to reform their several departments in accordance with the doctrines of their master, and, by the royal road of speculation, to reach at once the promised land and gather in the harvest, which had hitherto only been approached by long and laborious study. And so, for some time, a hard and fast line was drawn between the moral and the physical sciences; in fact, the very name of science was often denied to the latter.

The feud did not long subsist in its original intensity. The physical sciences proved conspicuously, by a brilliant series of discoveries and practical applications, that they contained a healthy germ of extraordinary fertility; it was impossible any longer to withhold from them recognition and respect. And even in other departments of science, conscientious investigators of facts soon protested against the over-bold flights of speculation. Still, it cannot be overlooked that the philosophy of Hegel and Schelling did exercise a beneficial influence; since their time the attention of investigators in the moral sciences had been constantly and more keenly directed to the scope of those

sciences, and to their intellectual contents, and therefore the great amount of labour bestowed on those systems has not been entirely thrown away.

We see, then, that in proportion as the experimental investigation of facts has recovered its importance in the moral sciences, the opposition between them and the physical sciences has become less and less marked. Yet we must not forget that, though this opposition was brought out in an unnecessarily exaggerated form by the Hegelian philosophy, it has its foundation in the nature of things, and must, sooner or later, make itself felt. It depends partly on the nature of the intellectual processes the two groups of sciences involve, partly, as their very names imply, on the subjects of which they treat. It is not easy for a scientific man to convey to a scholar or a jurist a clear idea of a complicated process of nature; he must demand of them a certain power of abstraction from the phenomena, as well as a certain skill in the use of geometrical and mechanical conceptions, in which it is difficult for them to follow him. On the other hand an artist or a theologian will perhaps find the natural philosopher too much inclined to mechanical and material explanations, which seem to them commonplace, and chilling to their feeling and enthusiasm. Nor will the scholar or the historian, who have some common ground with the theologian and the jurist, fare better with the natural philosopher. They will find him shockingly indifferent to literary treasures, perhaps even more indifferent than he ought to be to the history of his own science. In short, there is no denying that, while the moral sciences deal directly with the nearest and dearest interests of the human mind, and with the institutions it has brought into being, the natural sciences are concerned with dead, indifferent matter, obviously indispensable for the sake of its practical utility, but apparently without any immediate bearing on the cultivation of the intellect.

It has been shown, then, that the sciences have branched out into countless ramifications, that there has grown up between different groups of them a real and deeply felt opposition, that finally no single intellect can embrace the whole range

or even a considerable portion of it. Is it still reasonable to keep them together in one place of education? Is the union of the four faculties to form one University a mere relic of the Middle Ages? Many valid arguments have been adduced for separating them. Why not dismiss the medical faculty to the hospitals of our great towns, the scientific men to the Polytechnic Schools, and form special seminaries for the theologians and jurists? Long may the German universities be preserved from such a fate! Then, indeed, would the connection between the different sciences be finally broken. How essential that connection is, not only from an university point of view, as tending to keep alive the intellectual energy of the country, but also on material grounds, to secure the successful application of that energy, will be evident from a few considerations.

First, then, I would say that union of the different faculties is necessary to maintain a healthy equilibrium among the intellectual energies of students. Each study tries certain of our intellectual faculties more than the rest, and strengthens them accordingly by constant exercise. But any sort of one-sided development is attended with danger; it disqualifies us for using those faculties that are less exercised, and so renders us less capable of a general view; above all it leads us to overvalue ourselves. Any one who has found himself much more successful than others in some one department of intellectual labour, is apt to forget that there are many other things which they can do better than he can: a mistake—I would have every student remember—which is the worst enemy of all intellectual activity.

How many men of ability have forgotten to practise that criticism of themselves which is so essential to the student, and so hard to exercise, or have been completely crippled in their progress, because they have thought dry, laborious drudgery beneath them, and have devoted all their energies to the quest of brilliant theories and wonder-working discoveries! How many such men have become bitter misanthropes, and put an end to a melancholy existence, because they have failed to obtain among their fellows that recognition which must be won by

labour and results, but which is ever withheld from mere self-conscious genius ! And the more isolated a man is, the more liable is he to this danger ; while, on the other hand, nothing is more inspiring than to feel yourself forced to strain every nerve to win the admiration of men whom you, in your turn, must admire.

In comparing the intellectual processes involved in the pursuit of the several branches of science, we are struck by certain generic differences, dividing one group of sciences from another. At the same time it must not be forgotten that every man of conspicuous ability has his own special mental constitution which fits him for one line of thought rather than another. Compare the work of two contemporary investigators even in closely allied branches of science, and you will generally be able to convince yourself that the more distinguished the men are the more clearly does their individuality come out, and the less qualified would either of them be to carry on the other's researches. To-day I can, of course, do nothing more than characterise some of the most general of these differences.

I have already noticed the enormous mass of the materials accumulated by science. It is obvious that the organisation and arrangement of them must be proportionately perfect, if we are not to be hopelessly lost in the maze of erudition. One of the reasons why we can so far surpass our predecessors in each individual study is that they have shown us how to organise our knowledge.

This organisation consists, in the first place, of a mechanical arrangement of materials, such as is to be found in our catalogues, lexicons, registers, indexes, digests, scientific and literary annuals, systems of natural history, and the like. By these appliances thus much at least is gained, that such knowledge as cannot be carried about in the memory is immediately accessible to anyone who wants it. With a good lexicon a school-boy of the present day can achieve results in the interpretation of the classics which an Erasmus, with the erudition of a lifetime, could hardly attain. Works of this kind form, so to speak, our intellectual principal with the interest of which we trade : it is, so to speak, like capital invested in land. The

learning buried in catalogues, lexicons, and indexes looks as bare and uninviting as the soil of a farm; the uninitiated cannot see or appreciate the labour and capital already invested there; to them the work of the ploughman seems infinitely dull, weary, and monotonous. But though the compiler of a lexicon or of a system of natural history must be prepared to encounter labour as weary and as obstinate as the ploughman's, yet it need not be supposed that his work is of a low type, or that it is by any means as dry and mechanical as it looks when we have it before us in black and white. In this, as in any other sort of scientific work, it is necessary to discover every fact by careful observation, then to verify and collate them, and to separate what is important from what is not. All this requires a man with a thorough grasp both of the object of the compilation and of the matter and methods of the science; and for such a man every detail has its bearing on the whole, and its special interest. Otherwise dictionary-making would be the vilest drudgery imaginable.¹ That the influence of the progressive development of scientific ideas extends to these works is obvious from the constant demand for new lexicons, new natural histories, new digests, new catalogues of stars, all denoting advancement in the art of methodising and organising science.

But our knowledge is not to lie dormant in the shape of catalogues. The very fact that we must carry it about in black and white shows that our intellectual mastery of it is incomplete. It is not enough to be acquainted with the facts; scientific knowledge begins only when their laws and their causes are unveiled. Our materials must be worked up by a logical process; and the first step is to connect like with like, and to elaborate a general conception embracing them all. Such a conception, as the name implies, takes a number of single facts together, and stands as their representative in our mind. We call it a general conception, or the conception of a genus, when it embraces a number of existing objects; we call it a law when it embraces a series of incidents or occurrences. When, for example, I have

¹ *Condendaque lexica mandat damnatis.*—TR.

made out that all mammals—that is, all warm-blooded, viviparous animals—breathe through lungs, have two chambers in the heart, and at least three tympanal bones, I need no longer remember these anatomical peculiarities in the individual cases of the monkey, the dog, the horse, and the whale; the general rule includes a vast number of single instances, and represents them in my memory. When I enunciate the law of refraction, not only does this law embrace all cases of rays falling at all possible angles on a plane surface of water, and inform me of the result, but it includes all cases of rays of any colour incident on transparent surfaces of any form and any constitution whatsoever. This law, therefore, includes an infinite number of cases, which it would have been absolutely impossible to carry in one's memory. Moreover, it should be noticed that not only does this law include the cases which we ourselves or other men have already observed, but that we shall not hesitate to apply it to new cases, not yet observed, with absolute confidence in the reliability of our results. In the same way, if we were to find a new species of mammal, not yet dissected, we are entitled to assume, with a confidence bordering on a certainty, that it has lungs, two chambers in the heart, and three or more tympanal bones.

Thus, when we combine the results of experience by a process of thought, and form conceptions, whether general conceptions or laws, we not only bring our knowledge into a form in which it can be easily used and easily retained, but we actually enlarge it, inasmuch as we feel ourselves entitled to extend the rules and the laws we have discovered to all similar cases that may be hereafter presented to us.

The above-mentioned examples are of a class in which the mental process of combining a number of single cases so as to form conceptions is unattended by farther difficulties, and can be distinctly followed in all its stages. But in complicated cases it is not so easy completely to separate like facts from unlike, and to combine them into a clear well-defined conception. Assume that we know a man to be ambitious; we shall perhaps be able to predict with tolerable certainty that if he has to act under

certain conditions, he will follow the dictates of his ambition, and decide on a certain line of action. But, in the first place, we cannot define with absolute precision what constitutes an ambitious man, or by what standard the intensity of his ambition is to be measured; nor, again, can we say precisely what degree of ambition must operate in order to impress the given direction on the actions of the man under those particular circumstances. Accordingly, we institute comparisons between the actions of the man in question, as far as we have hitherto observed them, and those of other men who in similar cases have acted as he has done, and we draw our inference respecting his future actions without being able to express either the major or the minor premiss in a clear, sharply defined form—perhaps even without having convinced ourselves that our anticipation rests on such an analogy as I have described. In such cases our decision proceeds only from a certain psychological instinct, not from conscious reasoning, though in reality we have gone through an intellectual process identical with that which leads us to assume that a newly discovered mammal has lungs.

This latter kind of induction, which can never be perfectly assimilated to forms of logical reasoning, nor pressed so far as to establish universal laws, plays a most important part in human life. The whole of the process by which we translate our sensations into perceptions depends upon it, as appears especially from the investigation of what are called illusions. For instance, when the retina of the eye is irritated by a blow, we imagine we see a light in our field of vision, because we have, throughout our lives, felt irritation in the optic nerves only when there was light in the field of vision, and have become accustomed to identify the sensations of those nerves with the presence of light in the field of vision. Moreover, such is the complexity of the influences affecting the formation both of character in general and of the mental condition at any given moment, that this same kind of induction necessarily plays a leading part in the investigation of psychological processes. In fact, in ascribing to ourselves free-will, that is, full power to act as we please without being subject to a stern inevitable law of

causality, we deny *in toto* the possibility of referring at least one of the ways in which our mental activity expresses itself to a rigorous law.

We might possibly, in opposition to *logical induction* which reduces a question to clearly defined universal propositions, call this kind of reasoning *æsthetic induction*, because it is most conspicuous in the higher class of works of art. It is an essential part of an artist's talent to reproduce by words, by form, by colour, or by music, the external indications of a character or a state of mind, and by a kind of instinctive intuition, uncontrolled by any definable rule, to seize the necessary steps by which we pass from one mood to another. If we do find that the artist has consciously worked after general rules and abstractions, we think his work poor and commonplace, and cease to admire. On the contrary, the works of great artists bring before us characters and moods with such a lifelikeness, with such a wealth of individual traits and such an overwhelming conviction of truth, that they almost seem to be more real than the reality itself, because all disturbing influences are eliminated.

Now if, after these reflections, we proceed to review the different sciences, and to classify them according to the method by which they must arrive at their results, we are brought face to face with a generic difference between the natural and the moral sciences. The natural sciences are for the most part in a position to reduce their inductions to sharply defined general rules and principles; the moral sciences, on the other hand, have, in by far the most numerous cases, to do with conclusions arrived at by psychological instinct. Philology, in so far as it is concerned with the interpretation and emendation of the texts handed down to us, must seek to feel out, as it were, the meaning which the author intended to express, and the accessory notions which he wished his words to suggest; and for that purpose it is necessary to start with a correct insight, both into the personality of the author, and into the genius of the language in which he wrote. All this affords scope for *æsthetic*, but not for strictly logical, induction. It is only possible to pass judgment, if you have ready in your memory a great number of

similar facts, to be instantaneously confronted with the question you are trying to solve. Accordingly, one of the first requisites for studies of this class is an accurate and ready memory. Many celebrated historians and philologists have, in fact, astounded their contemporaries by their extraordinary strength of memory. Of course memory alone is insufficient without a knack of everywhere discovering real resemblance, and without a delicately and fully trained insight into the springs of human action; while this again is unattainable without a certain warmth of sympathy and an interest in observing the working of other men's minds. Intercourse with our fellow-men in daily life must lay the foundation of this insight, but the study of history and art serves to make it richer and completer, for there we see men acting under comparatively unusual conditions, and thus come to appreciate the full scope of the energies which lie hidden in our breasts.

None of this group of sciences, except grammar, lead us, as a rule, to frame and enunciate general laws, valid under all circumstances. The laws of grammar are a product of the human will, though they can hardly be said to have been framed deliberately, but rather to have grown up gradually, as they were wanted. Accordingly, they present themselves to a learner rather in the form of commands, that is, of laws imposed by external authority.

With these sciences theology and jurisprudence are naturally connected. In fact, certain branches of history and philology serve both as stepping-stones and as handmaids to them. The general laws of theology and jurisprudence are likewise commands, laws imposed by external authority to regulate, from a moral or juridical point of view, the actions of mankind; not laws which, like those of nature, contain generalisations from a vast multitude of facts. At the same time the application of a grammatical, legal, moral, or theological rule is couched, like the application of a law of nature to a particular case, in the forms of logical inference. The rule forms the major premiss of the syllogism, while the minor must settle whether the case in question satisfies the conditions to which the rule is intended to

apply. The solution of this latter problem, whether in grammatical analysis, where the meaning of a sentence is to be evolved, or in the legal criticism of the credibility of the facts alleged, of the intentions of the parties, or of the meaning of the documents they have put into court, will, in most cases, be again a matter of psychological insight. On the other hand, it should not be forgotten that both the syntax of fully developed languages and a system of jurisprudence gradually elaborated, as ours has been, by the practice of more than 2,000 years,¹ have reached a high pitch of logical completeness and consistency; so that, speaking generally, the cases which do not obviously fall under some one or other of the laws actually laid down are quite exceptional. Such exceptions there will always be, for the legislation of man can never have the absolute consistency and perfection of the laws of nature. In such cases there is no course open but to try and guess the intention of the legislator; or, if needs be, to supplement it after the analogy of his decisions in similar cases.

Grammar and jurisprudence have a certain advantage as means of training the intellect, inasmuch as they tax pretty equally all the intellectual powers. On this account secondary education among modern European nations is based mainly upon the grammatical study of foreign languages. The mother-tongue and modern foreign languages, when acquired solely by practice, do not call for any conscious logical exercise of thought, though we may cultivate by means of them an appreciation for artistic beauty of expression. The two classical languages, Latin and Greek, have, besides their exquisite logical subtlety and æsthetic beauty, an additional advantage, which they seem to possess in common with most ancient and original languages—they indicate accurately the relations of words and sentences to each other by numerous and distinct inflexions. Languages are, as it were, abraded by long use; grammatical distinctions are cut down to a minimum for the sake of brevity and rapidity

¹ It should be remembered that the Roman law, which has only partially and indirectly influenced English practice, is the recognised basis of German jurisprudence.—TR.

of expression, and are thus made less and less definite, as is obvious from the comparison of any modern European language with Latin; in English the process has gone further than in any other. This seems to me to be really the reason why the modern languages are far less fitted than the ancient for instruments of education.¹

As grammar is the staple of school education, legal studies are used, and rightly, as a means of training persons of maturer age, even when not specially required for professional purposes.

We now come to those sciences which, in respect of the kind of intellectual labour they require, stand at the opposite end of the series to philology and history; namely, the natural and physical sciences. I do not mean to say that in many branches even of these sciences an instinctive appreciation of analogies and a certain artistic sense have no part to play. On the contrary, in natural history the decision which characteristics are to be looked upon as important for classification, and which as unimportant, what divisions of the animal and vegetable kingdoms are more natural than others, is really left to an instinct of this kind, acting without any strictly definable rule. And it is a very suggestive fact that it was an artist, Goethe, who gave the first impulse to the researches of comparative anatomy into the analogy of corresponding organs in different animals, and to the parallel theory of the metamorphosis of leaves in the vegetable kingdom; and thus, in fact, really pointed out the direction which the science has followed ever since. But even in those departments of science where we have to do with the least understood vital processes, it is, speaking generally, far easier to make out general and comprehensive ideas and principles, and to express them in definite language, than in cases where we must base our judgment on the analysis of the human mind. It is only when we come to the experimental sciences to which mathematics are applied, and especially when we come to pure mathematics, that we

¹ Those to whom German is not a foreign tongue may, perhaps, be permitted to hold different views on the efficacy of modern languages in education.—Tr.

see the peculiar characteristics of the natural and physical sciences fully brought out.

The essential *differentia* of these sciences seems to me to consist in the comparative ease with which the individual results of observation and experiment are combined under general laws of unexceptionable validity and of an extraordinarily comprehensive character. In the moral sciences, on the other hand, this is just the point where insuperable difficulties are encountered. In mathematics the general propositions which, under the name of axioms, stand at the head of the reasoning, are so few in number, so comprehensive, and so immediately obvious, that no proof whatever is needed for them. Let me remind you that the whole of algebra and arithmetic is developed out of the three axioms:—

‘Things which are equal to the same things are equal to one another.’

‘If equals be added to equals, the wholes are equal.’

‘If unequals be added to equals, the wholes are unequal.’

And the axioms of geometry and mechanics are not more numerous. The sciences we have named are developed out of these few axioms by a continual process of deduction from them in more and more complicated cases. Algebra, however, does not confine itself to finding the sum of the most heterogeneous combinations of a finite number of magnitudes, but in the higher analysis it teaches us to sum even infinite series, the terms of which increase or diminish according to the most various laws; to solve, in fact, problems which could never be completed by direct addition. An instance of this kind shows us the conscious logical activity of the mind in its purest and most perfect form. On the one hand we see the laborious nature of the process, the extreme caution with which it is necessary to advance, the accuracy required to determine exactly the scope of such universal principles as have been attained, the difficulty of forming and understanding abstract conceptions. On the other hand, we gain confidence in the certainty, the range, and the fertility of this kind of intellectual work.

The fertility of the method comes out more strikingly in

applied mathematics, especially in mathematical physics, including, of course, physical astronomy. From the time when Newton discovered, by analysing the motions of the planets on mechanical principles, that every particle of ponderable matter in the universe attracts every other particle with a force varying inversely as the square of the distance, astronomers have been able, in virtue of that one law of gravitation, to calculate with the greatest accuracy the movements of the planets to the remotest past and the most distant future, given only the position, velocity, and mass of each body of our system at any one time. More than that, we recognise the operation of this law in the movements of double stars, whose distances from us are so great that their light takes years to reach us; in some cases, indeed, so great that all attempts to measure them have failed.

This discovery of the law of gravitation and its consequences is the most imposing achievement that the logical power of the human mind has hitherto performed. I do not mean to say that there have not been men who in power of abstraction have equalled or even surpassed Newton and the other astronomers, who either paved the way for his discovery, or have carried it out to its legitimate consequences; but there has never been presented to the human mind such an admirable subject as those involved and complex movements of the planets, which hitherto had served merely as food for the astrological superstitions of ignorant star-gazers, and were now reduced to a single law, capable of rendering the most exact account of the minutest detail of their motions.

The principles of this magnificent discovery have been successfully applied to several other physical sciences, among which physical optics and the theory of electricity and magnetism are especially worthy of notice. The experimental sciences have one great advantage over the natural sciences in the investigation of general laws of nature: they can change at pleasure the conditions under which a given result takes place, and can thus confine themselves to a small number of characteristic instances, in order to discover the law. Of course its validity must then

stand the test of application to more complex cases. Accordingly the physical sciences, when once the right methods have been discovered, have made proportionately rapid progress. Not only have they allowed us to look back into primæval chaos, where nebulous masses were forming themselves into suns and planets, and becoming heated by the energy of their contraction; not only have they permitted us to investigate the chemical constituents of the solar atmosphere and of the remotest fixed stars, but they have enabled us to turn the forces of surrounding nature to our own uses and to make them the ministers of our will.

Enough has been said to show how widely the intellectual processes involved in this group of sciences differ, for the most part, from those required by the moral sciences. The mathematician need have no memory whatever for detached facts, the physicist hardly any. Hypotheses based on the recollection of similar cases may, indeed, be useful to guide one into the right track, but they have no real value till they have led to a precise and strictly defined law. Nature does not allow us for a moment to doubt that we have to do with a rigid chain of cause and effect, admitting of no exceptions. Therefore to us, as her students, goes forth the mandate to labour on till we have discovered unvarying laws; till then we dare not rest satisfied, for then only can our knowledge grapple victoriously with time and space and the forces of the universe.

The iron labour of conscious logical reasoning demands great perseverance and great caution; it moves on but slowly, and is rarely illuminated by brilliant flashes of genius. It knows little of that facility with which the most varied instances come thronging into the memory of the philologist or the historian. Rather is it an essential condition of the methodical progress of mathematical reasoning that the mind should remain concentrated on a single point, undisturbed alike by collateral ideas on the one hand, and by wishes and hopes on the other, and moving on steadily in the direction it has deliberately chosen. A celebrated logician, Mr. John Stuart Mill, expresses his conviction that the inductive sciences have of late done more for the advance

of logical methods than the labours of philosophers properly so called. One essential ground for such an assertion must undoubtedly be that in no department of knowledge can a fault in the chain of reasoning be so easily detected by the incorrectness of the results as in those sciences in which the results of reasoning can be most directly compared with the facts of nature.

Though I have maintained that it is in the physical sciences, and especially in such branches of them as are treated mathematically, that the solution of scientific problems has been most successfully achieved, you will not, I trust, imagine that I wish to depreciate other studies in comparison with them. If the natural and physical sciences have the advantage of great perfection in form, it is the privilege of the moral sciences to deal with a richer material, with questions that touch more nearly the interests and the feelings of men, with the human mind itself, in fact, in its motives and the different branches of its activity. They have, indeed, the loftier and the more difficult task, but yet they cannot afford to lose sight of the example of their rivals, which, in form at least, have, owing to the more ductile nature of their materials, made greater progress. Not only have they something to learn from them in point of method, but they may also draw encouragement from the greatness of their results. And I do think that our age has learnt many lessons from the physical sciences. The absolute, unconditional reverence for facts, and the fidelity with which they are collected, a certain distrustfulness of appearances, the effort to detect in all cases relations of cause and effect, and the tendency to assume their existence, which distinguish our century from preceding ones, seem to me to point to such an influence.

I do not intend to go deeply into the question how far mathematical studies, as the representatives of conscious logical reasoning, should take a more important place in school education. But it is, in reality, one of the questions of the day. In proportion as the range of science extends, its system and organisation must be improved, and it must inevitably come about that individual students will find themselves compelled to go

through a stricter course of training than grammar is in a position to supply. What strikes me in my own experience of students who pass from our classical schools to scientific and medical studies, is, first, a certain laxity in the application of strictly universal laws. The grammatical rules in which they have been exercised are for the most part followed by long lists of exceptions; accordingly they are not in the habit of relying implicitly on the certainty of a legitimate deduction from a strictly universal law. Secondly, I find them for the most part too much inclined to trust to authority, even in cases where they might form an independent judgment. In fact, in philological studies, inasmuch as it is seldom possible to take in the whole of the premisses at a glance, and inasmuch as the decision of disputed questions often depends on an æsthetic feeling for beauty of expression, and for the genius of the language, attainable only by long training, it must often happen that the student is referred to authorities even by the best teachers. Both faults are traceable to a certain indolence and vagueness of thought, the sad effects of which are not confined to subsequent scientific studies. But certainly the best remedy for both is to be found in mathematics, where there is absolute certainty in the reasoning, and no authority is recognised but that of one's own intelligence.

So much for the several branches of science considered as exercises for the intellect, and as supplementing each other in that respect. But knowledge is not the sole object of man upon earth. Though the sciences arouse and educate the subtlest powers of the mind, yet a man who should study simply for the sake of knowing, would assuredly not fulfil the purpose of his existence. We often see men of considerable endowments, to whom their good or bad fortune has secured a comfortable livelihood or good social position, without giving them, at the same time, ambition or energy enough to make them work, dragging out a weary, unsatisfied existence, while all the time they fancy they are following the noblest aim of life by constantly devoting themselves to the increase of their knowledge, and the cultivation of their minds. Action alone gives a man a life

worth living ; and therefore he must aim either at the practical application of his knowledge, or at the extension of the limits of science itself. For to extend the limits of science is really to work for the progress of humanity. Thus we pass to the second link, uniting the different sciences, the connection, namely, between the subjects of which they treat.

Knowledge is power. Our age, more than any other, is in a position to demonstrate the truth of this maxim. We have taught the forces of inanimate nature to minister to the wants of human life and the designs of the human intellect. The application of steam has multiplied our physical strength a million-fold ; weaving and spinning machines have relieved us of labours the only merit of which consisted in a deadening monotony. The intercourse between men, with its far-reaching influence on material and intellectual progress, has increased to an extent of which no one could have even dreamed within the lifetime of the older among us. But it is not merely on the machines by which our powers are multiplied ; not merely on rifled cannon and armour-plated ships ; not merely on accumulated stores of money and the necessities of life, that the power of a nation rests : though these things have exercised so unmistakable an influence that even the proudest and most obstinate despotisms of our times have been forced to think of removing restrictions on industry, and of conceding to the industrious middle classes a due voice in their councils. But political organisation, the administration of justice, and the moral discipline of individual citizens are no less important conditions of the preponderance of civilised nations ; and so surely as a nation remains inaccessible to the influences of civilisation in these respects, so surely is it on the high road to destruction. The several conditions of national prosperity act and react on each other ; where the administration of justice is uncertain, where the interests of the majority cannot be asserted by legitimate means, the development of the national resources, and of the power depending upon them, is impossible ; nor, again, is it possible to make good soldiers except out of men who have learnt under just laws to educate the sense of honour that characterises an

independent man, certainly not out of those who have lived the submissive slaves of a capricious tyrant.

Accordingly every nation is interested in the progress of knowledge on the simple ground of self-preservation, even were there no higher wants of an ideal character to be satisfied; and not merely in the development of the physical sciences, and their technical application, but also in the progress of legal, political, and moral sciences, and of the accessory historical and philological studies. No nation which would be independent and influential can afford to be left behind in the race. Nor has this escaped the notice of the cultivated peoples of Europe. Never before was so large a part of the public resources devoted to universities, schools, and scientific institutions. We in Heidelberg have this year occasion to congratulate ourselves on another rich endowment granted by our government and our parliament.

I was speaking, at the beginning of my address, of the increasing division of labour and the improved organisation among scientific workers. In fact, men of science form, as it were, an organised army labouring on behalf of the whole nation, and generally under its direction and at its expense, to augment the stock of such knowledge as may serve to promote industrial enterprise, to increase wealth, to adorn life, to improve political and social relations, and to further the moral development of individual citizens. After the immediate practical results of their work we forbear to inquire; that we leave to the uninstructed. We are convinced that whatever contributes to the knowledge of the forces of nature or the powers of the human mind is worth cherishing, and may, in its own due time, bear practical fruit, very often where we should least have expected it. Who, when Galvani touched the muscles of a frog with different metals, and noticed their contraction, could have dreamt that eighty years afterwards, in virtue of the self-same process, whose earliest manifestations attracted his attention in his anatomical researches, all Europe would be traversed with wires, flashing intelligence from Madrid to St. Petersburg with the speed of lightning? In the hands of Galvani, and at first even in Volta's, electrical currents were phenomena capable of exerting

only the feeblest forces, and could not be detected except by the most delicate apparatus. Had they been neglected, on the ground that the investigation of them promised no immediate practical result, we should now be ignorant of the most important and most interesting of the links between the various forces of nature. When young Galileo, then a student at Pisa, noticed one day during divine service a chandelier swinging backwards and forwards, and convinced himself, by counting his pulse, that the duration of the oscillations was independent of the arc through which it moved, who could know that this discovery would eventually put it in our power, by means of the pendulum, to attain an accuracy in the measurement of time till then deemed impossible, and would enable the storm-tossed seaman in the most distant oceans to determine in what degree of longitude he was sailing?

Whoever, in the pursuit of science, seeks after immediate practical utility, may generally rest assured that he will seek in vain. All that science can achieve is a perfect knowledge and a perfect understanding of the action of natural and moral forces. Each individual student must be content to find his reward in rejoicing over new discoveries, as over new victories of mind over reluctant matter, or in enjoying the æsthetic beauty of a well-ordered field of knowledge, where the connection and the filiation of every detail is clear to the mind, and where all denotes the presence of a ruling intellect; he must rest satisfied with the consciousness that he too has contributed something to the increasing fund of knowledge on which the dominion of man over all the forces hostile to intelligence reposes. He will, indeed, not always be permitted to expect from his fellow-men appreciation and reward adequate to the value of his work. It is only too true that many a man to whom a monument has been erected after his death would have been delighted to receive during his lifetime a tenth part of the money spent in doing honour to his memory. At the same time, we must acknowledge that the value of scientific discoveries is now far more fully recognised than formerly by public opinion, and that instances of the authors of great advance in science starving in obscurity have

become rarer and rarer. On the contrary, the governments and peoples of Europe have, as a rule, admitted it to be their duty to recompense distinguished achievements in science by appropriate appointments or special rewards.

The sciences have then, in this respect, all one common aim, to establish the supremacy of intelligence over the world: while the moral sciences aim directly at making the resources of intellectual life more abundant and more interesting, and seek to separate the pure gold of truth from alloy, the physical sciences are striving indirectly towards the same goal, inasmuch as they labour to make mankind more and more independent of the material restraints that fetter their activity. Each student works in his own department, he chooses for himself those tasks for which he is best fitted by his abilities and his training. But each one must be convinced that it is only in connection with others that he can further the great work, and that therefore he is bound, not only to investigate, but to do his utmost to make the results of his investigation completely and easily accessible. If he does this, he will derive assistance from others, and will in his turn be able to render them his aid. The annals of science abound in evidence how such mutual services have been exchanged, even between departments of science apparently most remote. Historical chronology is essentially based on astronomical calculations of eclipses, accounts of which are preserved in ancient histories. Conversely, many of the important data of astronomy—for instance, the invariability of the length of the day, and the periods of several comets—rest upon ancient historical notices. Of late years, physiologists, especially Brücke, have actually undertaken to draw up a complete system of all the vocables that can be produced by the organs of speech, and to base upon it propositions for an universal alphabet, adapted to all human languages. Thus physiology has entered the service of comparative philology, and has already succeeded in accounting for many apparently anomalous substitutions, on the ground that they are governed, not as hitherto supposed, by the laws of euphony, but by similarity between the movements of the mouth that produce them. Again, comparative philology gives us

information about the relationships, the separations, and the migrations of tribes in prehistoric times, and of the degree of civilisation which they had reached at the time when they parted. For the names of objects to which they had already learnt to give distinctive appellations reappear as words common to their later languages. So that the study of languages actually gives us historical data for periods respecting which no other historical evidence exists.¹ Yet again I may notice the help which not only the sculptor, but the archæologist, concerned with the investigation of ancient statues, derives from anatomy. And if I may be permitted to refer to my own most recent studies, I would mention that it is possible, by reference to physical acoustics and to the physiological theory of the sensation of hearing, to account for the elementary principles on which our musical system is constructed, a problem essentially within the sphere of æsthetics. In fact, it is a general principle that the physiology of the organs of sense is most intimately connected with psychology, inasmuch as physiology traces in our sensations the results of mental processes which do not fall within the sphere of consciousness, and must therefore have remained inaccessible to us.

I have been able to quote only some of the most striking instances of this interdependence of different sciences, and such as could be explained in a few words. Naturally, too, I have tried to choose them from the most widely separated sciences. But far wider is of course the influence which allied sciences exert upon each other. Of that I need not speak, for each of you knows it from his own experience.

In conclusion, I would say, let each of us think of himself, not as a man seeking to gratify his own thirst for knowledge, or to promote his own private advantage, or to shine by his own abilities, but rather as a fellow-labourer in one great common work bearing upon the highest interests of humanity. Then assuredly we shall not fail of our reward in the approval of our own conscience and the esteem of our fellow-citizens.

¹ See, for example, Mommsen's *Rome*, Book I. ch. ii.—Tr.

To keep up these relations between all searchers after truth and all branches of knowledge, to animate them all to vigorous co-operation towards their common end, is the great office of the Universities. Therefore is it necessary that the four faculties should ever go hand in hand, and in this conviction will we strive, so far as in us lies, to press onward to the fulfilment of our great mission.

ON

GOETHE'S SCIENTIFIC RESEARCHES.

A Lecture delivered before the German Society of Königsberg, in the Spring of 1853.

It could not but be that Goethe, whose comprehensive genius was most strikingly apparent in that sober clearness with which he grasped and reproduced with lifelike freshness the realities of nature and human life in their minutest details, should, by those very qualities of his mind, be drawn towards the study of physical science. And in that department, he was not content with acquiring what others could teach him, but he soon attempted, as so original a mind was sure to do, to strike out an independent and a very characteristic line of thought. He directed his energies not only to the descriptive but also to the experimental sciences; the chief results being his botanical and osteological treatises on the one hand, and his theory of colour on the other. The first germs of these researches belong for the most part to the last decade of the eighteenth century, though some of them were not completed nor published till later. Since that time science has not only made great progress but has widely extended its range. It has assumed in some respects an entirely new aspect, it has opened out new fields of research and undergone many changes in its theoretical views. I shall attempt in the following Lecture to sketch the relation of Goethe's researches to the present standpoint of science, and to bring out the guiding idea that is common to them all.

The peculiar character of the descriptive sciences—botany, zoology, anatomy, and the like—is a necessary result of the work imposed upon them. They undertake to collect and sift an enormous mass of facts, and, above all, to bring them into a logical order or system. Up to this point their work is only the dry task of a lexicographer; their system is nothing more than a muniment-room in which the accumulation of papers is so arranged that any one can find what he wants at any moment. The more intellectual part of their work and their real interest only begins when they attempt to feel after the scattered traces of law and order in the disjointed, heterogeneous mass, and out of it to construct for themselves an orderly system, accessible at a glance, in which every detail has its due place, and gains additional interest from its connection with the whole.

In such studies, both the organising capacity and the insight of our poet found a congenial sphere—the epoch was moreover propitious to him. He found ready to his hand a sufficient store of logically arranged materials in botany and comparative anatomy, copious and systematic enough to admit of a comprehensive view, and to indicate the way to some happy glimpse of an all-pervading law; while his contemporaries, if they made any efforts in this direction, wandered without a compass, or else they were so absorbed in the dry registration of facts, that they scarcely ventured to think of anything beyond. It was reserved for Goethe to introduce two ideas of infinite fruitfulness.

The first was the conception that the differences in the anatomy of different animals are to be looked upon as variations from a common phase or type, induced by differences of habit, locality, or food. The observation which led him to this fertile conception was by no means a striking one; it is to be found in a monograph on the intermaxillary bone, written as early as 1786. It was known that in most vertebrate animals (that is, mammalia, birds, amphibia, and fishes) the upper jaw consists of two bones, the upper jaw-bone and the intermaxillary bone. The former always contains in the mammalia the molar and the canine teeth, the latter the incisors. Man, who is dis-

tinguished from all other animals by the absence of the projecting snout, has, on the contrary, on each side only one bone, the upper jaw-bone, containing all the teeth. This being so, Goethe discovered in the *human* skull faint traces of the sutures which in animals unite the upper and middle jaw-bones, and concluded from it that man had originally possessed an intermaxillary bone, which had subsequently coalesced with the upper jaw-bone. This obscure fact opened up to him a source of the most intense interest in the field of osteology, generally so much decried as the driest of studies. That details of structure should be the same in man and in animals when the parts continue to perform similar functions had involved nothing extraordinary. In fact, Camper had already attempted, on this principle, to trace similarities of structure even between man and fishes. But the persistence of this similarity, at least in a rudimentary form, even in a case when it evidently does not correspond to any of the requirements of the complete human structure, and consequently needs to be adapted to them by the coalescence of two parts originally separate, was what struck Goethe's far-seeing eye, and suggested to him a far more comprehensive view than had hitherto been taken. Further studies soon convinced him of the universality of his newly discovered principle, so that in 1795 and 1796 he was able to define more clearly the idea that had struck him in 1786, and to commit it to writing in his 'Sketch of a General Introduction to Comparative Anatomy.' He there lays down with the utmost confidence and precision that all differences in the structure of animals must be looked upon as variations of a single primitive type, induced by the coalescence, the alteration, the increase, the diminution, or even the complete removal of single parts of the structure; the very principle, in fact, which has become the leading idea of comparative anatomy in its present stage. Nowhere has it been better or more clearly expressed than in Goethe's writings. Subsequent authorities have made but few essential alterations in his theory. The most important of these is, that we no longer undertake to construct a common type for the whole animal kingdom, but are content

with one for each of Cuvier's great divisions. The industry of Goethe's successors has accumulated a well-sifted stock of facts, infinitely more copious than what he could command, and has followed up successfully into the minutest details what he could only indicate in a general way.

The second leading conception which science owes to Goethe enunciated the existence of an analogy between the different parts of one and the same organic being, similar to that which we have just pointed out as subsisting between corresponding parts of different species. In most organisms we see a great repetition of single parts. This is most striking in the vegetable kingdom; each plant has a great number of similar stem leaves, similar petals, similar stamens, and so on. According to Goethe's own account, the idea first occurred to him while looking at a fan-palm at Padua. He was struck by the immense variety of changes of form which the successively developed stem-leaves exhibit, by the way in which the first simple root leaflets are replaced by a series of more and more divided leaves, till we come to the most complicated.

He afterwards succeeded in discovering the transformation of stem-leaves into sepals and petals, and of sepals and petals into stamens, nectaries, and ovaries, and thus he was led to the doctrine of the metamorphosis of plants, which he published in 1790. Just as the anterior extremity of vertebrate animals takes different forms, becoming in man and in apes an arm, in other animals a paw with claws, or a forefoot with a hoof, or a fin, or a wing, but always retains the same divisions, the same position, and the same connection with the trunk, so the leaf appears as a cotyledon, stem-leaf, sepal, petal, stamen, nectary, ovary, &c., all resembling each other to a certain extent in origin and composition, and even capable, under certain unusual conditions, of passing from one form into the other, as, for example, may be seen by any one who looks carefully at a full-blown rose, where some of the stamens are completely, some of them partially, changed into petals. This view of Goethe's, like the other, is now completely adopted into science, and enjoys the universal assent of botanists, though of course some details are still

matters of controversy, as, for instance, whether the bud is a single leaf or a branch.

In the animal kingdom, the composition of an individual out of several similar parts is very striking in the great sub-kingdom of the articulatæ—for example, in insects and worms. The larva of an insect, or the caterpillar of a butterfly, consists of a number of perfectly similar segments; only the first and last of them differ, and that but slightly, from the others. After their transformation into perfect insects, they furnish clear and simple exemplifications of the view which Goethe had grasped in his doctrine of the metamorphosis of plants, the development, namely, of apparently very dissimilar forms from parts originally alike. The posterior segments retain their original simple form; those of the breastplate are drawn closely together, and develop feet and wings, while those of the head develop jaws and feelers; so that in the perfect insect, the original segments are recognised only in the posterior part of the body. In the vertebrata, again, a repetition of similar parts is suggested by the vertebral column, but has ceased to be observable in the external form. A fortunate glance at a broken sheep's skull, which Goethe found by accident on the sand of the Lido at Venice, suggested to him that the skull itself consisted of a series of very much altered vertebræ. At first sight, no two things can be more unlike than the broad uniform cranial cavity of the mammalia, inclosed by smooth plates, and the narrow cylindrical tube of the spinal marrow, composed of short, massy, jagged bones. It was a bright idea to detect the transformation in the skull of a mammal; the similarity is more striking in the amphibia and fishes. It should be added that Goethe left this idea unpublished for a long time, apparently because he was not quite sure how it would be received. Meantime, in 1806, the same idea occurred to Oken, who introduced it to the scientific world, and afterwards disputed with Goethe the priority of discovery. In fact, Goethe had waited till 1817, when the opinion had begun to find adherents, and then declared that he had had it in his mind for thirty years. Up to the present day the number and composition of the vertebræ of the skull are a

subject of controversy, but the principle has maintained its ground.

Goethe's views, however, on the existence of a common type in the animal kingdom do not seem to have exercised any direct influence on the progress of science. The doctrine of the metamorphosis of plants was introduced into botany as his distinct and recognised property; but his views on osteology were at first disputed by anatomists, and only subsequently attracted attention when the science had, apparently on independent grounds, found its way to the same discovery. He himself complains that his first ideas of a common type had encountered nothing but contradiction and scepticism at the time when he was working them out in his own mind, and that even men of the freshest and most original intellect, like the two Von Humboldts, had listened to them with something like impatience. But it is almost a matter of course that in any natural or physical science, theoretical ideas attract the attention of its cultivators only when they are advanced in connection with the whole of the evidence on which they rest, and thus justify their title to recognition. Be that as it may, Goethe is entitled to the credit of having caught the first glimpse of the guiding ideas to which the sciences of botany and anatomy were tending, and by which their present form is determined.

But great as is the respect which Goethe has secured by his achievements in the descriptive natural sciences, the denunciation heaped by all physicists on his researches in their department, and especially on his 'theory of colour,' is at least as uncompromising. This is not the place to plunge into the controversy that raged on the subject, and so I shall only attempt to state clearly the points at issue, and to explain what principle was involved, and what is the latent significance of the dispute.

To this end it is of some importance to go back to the history of the origin of the theory, and to its simplest form, because at that stage of the controversy the points at issue are obvious, and admit of easy and distinct statement, unincumbered by disputes about the correctness of detached facts and complicated theories.

Goethe himself describes very gracefully, in the confession at

the end of his 'Theory of Colour,' how he came to take up the subject. Finding himself unable to grasp the æsthetic principles involved in effects of colour, he resolved to resume the study of the physical theory, which he had been taught at the university, and to repeat for himself the experiments connected with it. With that view he borrowed a prism of Hofrath Bütter, of Jena, but was prevented by other occupations from carrying out his plan, and kept it by him for a long time unused. The owner of the prism, a very orderly man, after several times asking in vain, sent a messenger with instructions to bring it back directly. Goethe took it out of the case, and thought he would take one more peep through it. To make certain of seeing something, he turned it towards a long white wall, under the impression that as there was plenty of light there he could not fail to see a brilliant example of the resolution of light into different colours; a supposition, by the way, which shows how little Newton's theory of the phenomena was then present to his mind. Of course he was disappointed. On the white wall he saw no colours; they only appeared where it was bounded by darker objects. Accordingly he made the observation—which, it should be added, is fully accounted for by Newton's theory—that colour can only be seen through a prism where a dark object and a bright one have the same boundary. Struck by this observation, which was quite new to him, and convinced that it was irreconcilable with Newton's theory, he induced the owner of the prism to relent, and devoted himself to the question with the utmost zeal and interest. He prepared sheets of paper with black and white spaces, and studied the phenomenon under every variety of condition, until he thought he had sufficiently proved his rules. He next attempted to explain his supposed discovery to a neighbour, who was a physicist, and was disagreeably surprised to be assured by him that the experiments were well known, and fully accounted for in Newton's theory. Every other natural philosopher whom he consulted told him exactly the same, including even the brilliant Lichtenberg, whom he tried for a long time to convert, but in vain. He studied Newton's writings, and fancied he had found some

fallacies in them which accounted for the error. Unable to convince any of his acquaintances, he at last resolved to appear before the bar of public opinion, and in 1791 and 1792 published the first and second parts of his 'Contributions to Physical Optics.'

In that work he describes the appearances presented by white discs on a black ground, black discs on a white ground, and coloured discs on a black or white ground, when examined through a prism. As to the results of the experiments, there is no dispute whatever between him and the physicists. He describes the phenomena he saw with great truth to nature; the style is lively, and the arrangement such as to make a conspectus of them easy and inviting; in short, in this as in all other cases where facts are to be described, he proves himself a master. At the same time he expresses his conviction that the facts he has adduced are calculated to refute Newton's theory. There are two points especially which he considers fatal to it: first, that the centre of a broad white surface remains white when seen through a prism; and secondly, that even a black streak on a white ground can be entirely decomposed into colours.

Newton's theory is based on the hypothesis that there exists light of different kinds, distinguished from one another by the sensation of colour which they produce in the eye. Thus there is red, orange, yellow, green, blue, and violet light, and light of all intermediate colours. Different kinds of light, or differently coloured lights, produce, when mixed, derived colours, which to a certain extent resemble the original colours from which they are derived; to a certain extent form new tints. White is a mixture of all the before-named colours in certain definite proportions. But the primitive colours can always be reproduced by analysis from derived colours, or from white, while themselves incapable of analysis or change. The cause of the colours of transparent and opaque bodies is, that when white light falls upon them they destroy some of its constituents and send to the eye other constituents, but no longer mixed in the right proportions to produce white light. Thus a piece of red glass looks red because it transmits only red rays. Consequently all

colour is derived solely from a change in the proportions in which light is mixed, and is, therefore, a property of light, not of the coloured bodies, which only furnish an occasion for its manifestation.

A prism refracts transmitted light; that is to say, deflects it so that it makes a certain angle with its original direction; the rays of simple light of different colours have, according to Newton, different refrangibilities, and therefore, after refraction in the prism, pursue different courses and separate from each other. Accordingly a luminous point of infinitely small dimensions appears, when seen through the prism, to be first displaced, and, secondly, extended into a coloured line, the so-called prismatic spectrum, which shows what are called the primary colours in the order above-named. If, however, you look at a broader luminous surface, the spectra of the points near the middle are superposed, as may be seen from a simple geometrical investigation, in such proportions as to give white light, except at the edges, where certain of the colours are free. This white surface appears displaced, as the luminous point did; but instead of being coloured throughout, it has on one side a margin of blue and violet, on the other a margin of red and yellow. A black patch between two bright surfaces may be entirely covered by their coloured edges; and when these spectra meet in the middle, the red of the one and the violet of the other combine to form purple. Thus the colours into which, at first sight, it seems as if the black were analysed are in reality due, not to the black strip, but to the white on each side of it.

It is evident that at the first moment Goethe did not recollect Newton's theory well enough to be able to find out the physical explanation of the facts I have just glanced at. It was afterwards laid before him again and again, and that in a thoroughly intelligible form, for he speaks about it several times in terms that show he understood it quite correctly. But he is still so dissatisfied with it that he persists in his assertion that the facts just cited are of a nature to convince any one who observes them of the absolute incorrectness of Newton's theory. Neither here nor in his later controversial writings does he ever

clearly state in what he conceives the insufficiency of the explanation to consist. He merely repeats again and again that it is quite absurd. And yet I cannot see how any one, whatever his views about colour, can deny that the theory is perfectly consistent with itself; and that if the hypothesis from which it starts be granted, it explains the observed facts completely and even simply. Newton himself mentions these spurious spectra in several passages of his optical works, without going into any special elucidation of the point, considering, of course, that the explanation follows at once from his hypothesis. And he seems to have had good reason to think so; for Goethe no sooner began to call the attention of his scientific friends to the phenomena than all with one accord, as he himself tells us, met his difficulties with this explanation from Newton's principles, which, though not actually in his writings, instantly suggested itself to every one who knew them.

A reader who tries to realise attentively and thoroughly every step in this part of the controversy is apt to experience at this point an uncomfortable, almost a painful, feeling to see a man of extraordinary abilities persistently declaring that there is an obvious absurdity lurking in a few inferences apparently quite clear and simple. He searches and searches, and at last unable, with all his efforts, to find any such absurdity, or even the appearance of it, he gets into a state of mind in which his own ideas are, so to speak, crystallised. But it is just this obvious, flat contradiction that makes Goethe's point of view in 1792 so interesting and so important. At this point he has not as yet developed any theory of his own; there is nothing under discussion but a few easily grasped facts, as to the correctness of which both parties are agreed, and yet both hold distinctly opposite views; neither of them even understands what his opponent is driving at. On the one side are a number of physicists, who, by a long series of the ablest investigations, the most elaborate calculations, and the most ingenious inventions, have brought optics to such perfection that it, and it alone, among the physical sciences, was beginning almost to rival astronomy in accuracy. Some of them have made the pheno-

mena the subject of direct investigation ; all of them, thanks to the accuracy with which it is possible to calculate beforehand the result of every variety in the construction and combination of instruments, have had the opportunity of putting the inferences deduced from Newton's views to the test of experiment, and all, without exception, agree in accepting them. On the other side is a man whose remarkable mental endowments, and whose singular talent for seeing through whatever obscures reality, we have had occasion to recognise, not only in poetry, but also in the descriptive parts of the natural sciences ; and this man assures us with the utmost zeal that the physicists are wrong : he is so convinced of the correctness of his own view, that he cannot explain the contradiction except by assuming narrowness or malice on their part, and finally declares that he cannot help looking upon his own achievement in the theory of colour as far more valuable than anything he has accomplished in poetry.¹

So flat a contradiction leads us to suspect that there must be behind some deeper antagonism of principle, some difference of organisation between his mind and theirs, to prevent them from understanding each other. I will try to indicate in the following pages what I conceive to be the grounds of this antagonism.

Goethe, though he exercised his powers in many spheres of intellectual activity, is nevertheless, *par excellence*, a poet. Now in poetry, as in every other art, the essential thing is to make the material of the art, be it words, or music, or colour, the direct vehicle of an idea. In a perfect work of art, the idea must be present and dominate the whole, almost unknown to the poet himself, not as the result of a long intellectual process, but as inspired by a direct intuition of the inner eye, or by an outburst of excited feeling.

An idea thus embodied in a work of art, and dressed in the garb of reality, does indeed make a vivid impression by appealing directly to the senses, but loses, of course, that universality and that intelligibility which it would have had if presented in

¹ See Eckermann's *Conversations*

the form of an abstract notion. The poet, feeling how the charm of his works is involved in an intellectual process of this type, seeks to apply it to other materials. Instead of trying to arrange the phenomena of nature under definite conceptions, independent of intuition, he sits down to contemplate them as he would a work of art, complete in itself, and certain to yield up its central idea, sooner or later, to a sufficiently susceptible student. Accordingly, when he sees the skull on the Lido, which suggests to him the vertebral theory of the cranium, he remarks that it serves to revive his old belief, already confirmed by experience, that Nature has no secrets from the attentive observer. So again in his first conversation with Schiller on the 'Metamorphosis of Plants.' To Schiller, as a follower of Kant, the idea is the goal, ever to be sought, but ever unattainable, and therefore never to be exhibited as realised in a phenomenon. Goethe, on the other hand, as a genuine poet, conceives that he finds in the phenomenon the direct expression of the idea. He himself tells us that nothing brought out more sharply the separation between himself and Schiller. This, too, is the secret of his affinity with the natural philosophy of Schelling and Hegel, which likewise proceeds from the assumption that Nature shows us by direct intuition the several steps by which a conception is developed. Hence too the ardour with which Hegel and his school defended Goethe's scientific views. Moreover, this view of Nature accounts for the war which Goethe continued to wage against complicated experimental researches. Just as a genuine work of art cannot bear retouching by a strange hand, so he would have us believe Nature resists the interference of the experimenter who tortures her and disturbs her; and, in revenge, misleads the impertinent kill-joy by a distorted image of herself.

Accordingly, in his attack upon Newton he often sneers at spectra, tortured through a number of narrow slits and glasses, and commends the experiments that can be made in the open air under a bright sun, not merely as particularly easy and particularly enchanting, but also as particularly convincing! The poetic turn of mind is very marked even in his morphological

researches. If we only examine what has really been accomplished by the help of the ideas which he contributed to science, we shall be struck by the very singular relation which they bear to it. No one will refuse to be convinced if you lay before him the series of transformations by which a leaf passes into a stamen, an arm into a fin or a wing, a vertebra into the occipital bone. The idea that all the parts of a flower are modified leaves reveals a connecting law which surprises us into acquiescence. But now try and define the leaf-like organ, determine its essential characteristics, so as to include all the forms that we have named. You will find yourself in a difficulty, for all distinctive marks vanish, and you have nothing left, except that a leaf in the wider sense of the term is a lateral appendage of the axis of a plant. Try then to express the proposition 'the parts of the flower are modified leaves' in the language of scientific definition, and it reads, 'the parts of the flower are lateral appendages of the axis.' To see this does not require a Goethe. So again it has been objected, and not unjustly, to the vertebral theory, that it must extend the notion of a vertebra so much that nothing is left but the bare fact—a vertebra is a bone. We are equally perplexed if we try to express in clear scientific language what we mean by saying that such and such a part of one animal corresponds to such and such a part of another. We do not mean that their physiological use is the same, for the same piece which in bird serves as the lower jaw, becomes in mammals a tiny tympanal bone. Nor would the shape, the position, or the connection of the part in question with other parts serve to identify it in all cases. But yet it has been found possible in most cases, by following the intermediate steps, to determine with tolerable certainty which parts correspond to each other. Goethe himself said this very clearly: he says, in speaking of the vertebral theory of the skull, 'Such an *aperçu*, such an intuition, conception, representation, notion, idea, or whatever you choose to call it, always retains something esoteric and indefinable, struggle as you will against it; as a general principle, it may be enunciated, but cannot be proved; in detail it may be exhibited, but can never be put in a cut and

dry form.' And so, or nearly so, the problem stands to this day. The difference may be brought out still more clearly if we consider how physiology, which investigates the relations of vital processes as cause and effect, would have to treat this idea of a common type of animal structure. The science might ask, Is it, on the one hand, a correct view, that during the geological periods that have passed over the earth, one species has been developed from another, so that, for example, the breast-fin of the fish has gradually changed into an arm or a wing? Or again, shall we say that the different species of animals were created equally perfect—that the points of resemblance between them are to be ascribed to the fact that in all vertebrate animals the first steps in development from the egg can only be effected by Nature in one way, almost identical in all cases, and that the later analogies of structure are determined by these features, common to all embryos? Probably the majority of observers incline to the latter view,¹ for the agreement between the embryos of different vertebrate animals, in the earlier stages, is very striking. Thus even young mammals have occasionally rudimentary gills on the side of the neck, like fishes. It seems, in fact, that what are in the mature animals corresponding parts originate in the same way during the process of development, so that scientific men have lately begun to make use of embryology as a sort of check on the theoretical views of comparative anatomy. It is evident that by the application of the physiological views just suggested, the idea of a common type would acquire definiteness and meaning as a distinct scientific conception. Goethe did much : he saw by a happy intuition that there was a law, and he followed up the indications of it with great shrewdness. But what law it was he did not see ; nor did he even try to find it out. That was not in his line. Moreover, even in the present condition of science, a definite view on the question is impossible ; the very form in which it should be proposed is scarcely yet settled. And therefore we readily admit that in this department Goethe did all that was possible at the time when he lived. I said just now that he treated nature like a work of

¹ This was written before the appearance of Darwin's *Origin of Species*.

art. In his studies on morphology, he reminds one of a spectator at a play, with strong artistic sympathies. His delicate instinct makes him feel how all the details fall into their places, and work harmoniously together, and how some common purpose governs the whole; and yet while this exquisite order and symmetry give him intense pleasure he cannot formulate the dominant idea. That is reserved for the scientific critic of the drama, while the artistic spectator feels perhaps, as Goethe did in the presence of natural phenomena, an antipathy to such dissection, fearing, though without reason, that his pleasure may be spoilt by it.

Goethe's point of view in the Theory of Colour is much the same. We have seen that he rebels against the physical theory just at the point where it gives complete and consistent explanations from principles once accepted. Evidently it is not the insufficiency of the theory to explain individual cases that is a stumbling-block to him. He takes offence at the assumption made for the sake of explaining the phenomena, which seem to him so absurd, that he looks upon the interpretation as no interpretation at all. Above all, the idea that white light could be composed of coloured light seems to have been quite inconceivable to him; at the very beginning of the controversy, he rails at the disgusting Newtonian white of the natural philosophers, an expression which seems to show that this was the assumption that most annoyed him.

Again, in his later attacks on Newton, which were not published till after his Theory of Colour was completed, he rather strives to show that Newton's facts might be explained on his own hypothesis, and that therefore Newton's hypothesis was not fully proved, than attempts to prove that hypothesis inconsistent with itself or with the facts. Nay, he seems to consider the obviousness of his own hypothesis so overwhelming, that it need only be brought forward to upset Newton's entirely. There are only a few passages where he disputes the experiments described by Newton. Some of them, apparently, he could not succeed in refuting, because the result is not equally easy to observe in all positions of the lenses used, and because he was

unacquainted with the geometrical relations by which the most favourable positions of them are determined. In other experiments on the separation of simple coloured light by means of prisms alone, Goethe's objections are not quite groundless, inasmuch as the isolation of single colours cannot by this means be so effectually carried out, that after refraction through another prism there are no traces of other tints at the edges. A complete isolation of light of one colour can only be effected by very carefully arranged apparatus, consisting of combined prisms and lenses, a set of experiments which Goethe postponed to a supplement, and finally left unnoticed. When he complains of the complication of these contrivances, we need only think of the laborious and roundabout methods which chemists must often adopt to obtain certain elementary bodies in a pure form; and we need not be surprised to find that it is impossible to solve a similar problem in the case of light in the open air in a garden, and with a single prism in one's hand.¹ Goethe must, consistently with his theory, deny *in toto* the possibility of isolating pure light of one colour. Whether he ever experimented with the proper apparatus to solve the problem remains doubtful, as the supplement in which he promised to detail these experiments was never published.

To give some idea of the passionate way in which Goethe, usually so temperate and even courtier-like, attacks Newton, I quote from a few pages of the controversial part of his work the following expressions, which he applies to the propositions of this consummate thinker in physical and astronomical science—'incredibly impudent'; 'mere twaddle'; 'ludicrous explanation'; 'admirable for school-children in a go-cart'; 'but I see nothing will do but lying, and plenty of it.'²

¹ I venture to add that I am acquainted with the impossibility of decomposing or changing simple coloured light, the two principles which form the basis of Newton's theory, not merely by hearsay, but from actual observation, having been under the necessity in one of my own researches of obtaining light of one colour in a state of the greatest possible purity. (See Poggendorff's *Annalen*, vol. lxxxvi. p. 501, on Sir D. Brewster's *New Analysis of Sunlight*.)

² Something parallel to this extraordinary proceeding of Goethe's may be found in Hobbes's attack on Wallis.—TR.

Thus, in the theory of colour, Goethe remains faithful to his principle, that Nature must reveal her secrets of her own free will; that she is but the transparent representation of the ideal world. Accordingly, he demands, as a preliminary to the investigation of physical phenomena, that the observed facts shall be so arranged that one explains the other, and that thus we may attain an insight into their connection without ever having to trust to anything but our senses. This demand of his looks most attractive, but is essentially wrong in principle. For a natural phenomenon is not considered in physical science to be fully explained until you have traced it back to the ultimate forces which are concerned in its production and its maintenance. Now, as we can never become cognisant of forces *qua* forces, but only of their effects, we are compelled in every explanation of natural phenomena to leave the sphere of sense, and to pass to things which are not objects of sense, and are defined only by abstract conceptions. When we find a stove warm, and then observe that a fire is burning in it, we say, though somewhat inaccurately, that the former sensation is explained by the latter. But in reality this is equivalent to saying, we are always accustomed to find heat where fire is burning; now, a fire is burning in the stove, therefore we shall find heat there. Accordingly we bring our single fact under a more general, better-known fact, rest satisfied with it, and call it falsely an explanation. Evidently, however, the generality of the observation does not necessarily imply an insight into causes; such an insight is only obtained when we can make out what forces are at work in the fire, and how the effects depend upon them.

But this step into the region of abstract conceptions, which must necessarily be taken if we wish to penetrate to the causes of phenomena, scares the poet away. In writing a poem he has been accustomed to look, as it were, right into the subject, and to reproduce his intuition without formulating any of the steps that led him to it. And his success is proportionate to the vividness of the intuition. Such is the fashion in which he would have Nature attacked. But the natural philosopher insists on transporting him into a world of invisible atoms and

movements, of attractive and repulsive forces, whose intricate actions and reactions, though governed by strict laws, can scarcely be taken in at a glance. To him the impressions of sense are not an irrefragable authority; he examines what claim they have to be trusted; he asks whether things which they pronounce alike are really alike, and whether things which they pronounce different are really different; and often finds that he must answer, no! The result of such examination, as at present understood, is that the organs of sense do indeed give us information about external effects produced on them, but convey those effects to our consciousness in a totally different form, so that the character of a sensuous perception depends not so much on the properties of the object perceived as on those of the organ by which we receive the information. All that the optic nerve conveys to us, it conveys under the form of a sensation of light, whether it be the rays of the sun, or a blow in the eye, or an electric current passing through it. Again, the auditory nerve translates everything into phenomena of sound, the nerves of the skin into sensations of temperature or touch. The same electric current whose existence is indicated by the optic nerve as a flash of light, or by the organ of taste as an acid flavour, excites in the nerves of the skin the sensation of burning. The same ray of sunshine, which is called light when it falls on the eye, we call heat when it falls on the skin. But on the other hand, in spite of their different effects upon our organisation, the daylight which enters through our windows, and the heat radiated by an iron stove, do not in reality differ more or less from each other than the red and blue constituents of light. In fact, just as in the Undulatory Theory the red rays are distinguished from the blue rays only by their longer period of vibration, and their smaller refrangibility, so the dark heat rays of the stove have a still longer period and still smaller refrangibility than the red rays of light, but are in every other respect exactly similar to them. All these rays, whether luminous or non-luminous, have heating properties, but only a certain number of them, to which for that reason we give the name of light, can penetrate through the transparent part of the eye to the optic nerve, and excite a

sensation of light. Perhaps the relation between our senses and the external world may be best enunciated as follows : our sensations are for us only *symbols* of the objects of the external world, and correspond to them only in some such way as written characters or articulate words to the things they denote. They give us, it is true, information respecting the properties of things without us, but no better information than we give a blind man about colour by verbal descriptions.

We see that science has arrived at an estimate of the senses very different from that which was present to the poet's mind. And Newton's assertion that white was composed of all the colours of the spectrum was the first germ of the scientific view which has subsequently been developed. For at that time there were none of those galvanic observations which paved the way to a knowledge of the functions of the nerves in the production of sensations. Natural philosophers asserted that white, to the eye the simplest and purest of all our sensations of colour, was compounded of less pure and complex materials. It seems to have flashed upon the poet's mind that all his principles were unsettled by the results of this assertion, and that is why the hypothesis seems to him so unthinkable, so ineffably absurd. We must look upon his theory of colour as a forlorn hope, as a desperate attempt to rescue from the attacks of science the belief in the direct truth of our sensations. And this will account for the enthusiasm with which he strives to elaborate and to defend his theory, for the passionate irritability with which he attacks his opponent, for the overweening importance which he attaches to these researches in comparison with his other achievements, and for his inaccessibility to conviction or compromise.

If we now turn to Goethe's own theories on the subject, we must, on the grounds above stated, expect to find that he cannot, without being untrue to his own principle, give us anything deserving to be called a scientific explanation of the phenomena, and that is exactly what happens. He starts with the proposition that all colours are darker than white, that they have something of shade in them (on the physical theory, white compounded of all colours must necessarily be brighter than

any of its constituents). The direct mixture of dark and light, of black and white, gives grey; the colours must therefore owe their existence to some form of the co-operation of light and shade. Goethe imagines he has discovered it in the phenomena presented by slightly opaque or hazy media. Such media usually look blue when the light falls on them and they are seen in front of a dark object, but yellow when a bright object is looked at through them. Thus in the daytime the air looks blue against the dark background of the sky, and the sun, when viewed, as is the case at sunset, through a thick and hazy stratum of air, appears yellow. The physical explanation of this phenomenon, which, however, is not exhibited by all such media, as, for instance, by plates of unpolished glass, would lead us too far from the subject. According to Goethe, the semi-opaque medium imparts to the light something corporeal, something of the nature of shade, such as is requisite, he would say, for the formation of colour. This conception alone is enough to perplex any one who looks upon it as a physical explanation. Does he mean to say that material particles mingle with the light and fly away with it? But this is Goethe's fundamental experiment, this is the typical phenomenon under which he tries to reduce all the phenomena of colour, especially those connected with the prismatic spectrum. He looks upon all transparent bodies as slightly hazy, and assumes that the prism imparts to the image which it shows to an observer something of its own opacity. Here, again, it is hard to get a definite conception of what is meant. Goethe seems to have thought that a prism never gives perfectly defined images, but only indistinct, half-obliterated ones, for he puts them all in the same class with the double images which are exhibited by parallel plates of glass and by Iceland spar. The images formed by a prism are, it is true, indistinct in compound light, but they are perfectly defined when simple light is used. If you examine, he says, a bright surface on a dark ground through a prism, the image is displaced and blurred by the prism. The anterior edge is pushed forward over the dark background, and consequently a hazy light on a dark ground appears blue, while the other edge

is covered by the image of the black surface which comes after it, and, consequently, being a light image behind a hazy dark colour, appears yellowish-red. But why the anterior edge appears in front of the ground, the posterior edge behind it, and not *vice versa*, he does not explain. Let us analyse this explanation, and try to grasp clearly the conception of an optical image. When I see a bright object reflected in a mirror, the reason is that the light which proceeds from it is thrown back exactly as if it came from an object of the same kind behind the mirror. The eye of the observer receives the impression accordingly, and therefore he imagines he really sees the object. Every one knows there is nothing real behind the mirror to correspond to the image—that no light can penetrate thither, but that what is called the image is simply a geometrical point, in which the reflected rays, if produced backwards, would intersect. And, accordingly, no one expects the image to produce any real effect behind the mirror. In the same way the prism shows us images of objects which occupy a different position from the objects themselves; that is to say, the light which an object sends to the prism is refracted by it, so that it appears to come from an object lying to one side, called the image. This image, again, is not real; it is, as in the case of reflection, the geometrical point in which the refracted rays intersect when produced backwards. And yet, according to Goethe, this image is to produce real effects by its displacement; the displaced patch of light makes, he says, the dark space behind it appear blue, just as an imperfectly transparent body would, and so again the displaced dark patch makes the bright space behind appear reddish-yellow. That Goethe really treats the image as an actual object in the place it appears to occupy is obvious enough, especially as he is compelled to assume, in the course of his explanation, that the blue and red edges of the bright space are respectively before and behind the dark image which, like it, is displaced by the prism. He does, in fact, remain loyal to the appearance presented to the senses, and treats a geometrical locus as if it were a material object. Again, he does not scruple at one time to make red and blue destroy each other, as, for example, in the

blue edge of a red surface seen through the prism, and at another to construct out of them a beautiful purple, as when the blue and red edges of two neighbouring white surfaces meet in a black ground. And when he comes to Newton's more complicated experiments, he is driven to still more marvellous expedients. As long as you treat his explanations as a pictorial way of representing the physical processes, you may acquiesce in them, and even frequently find them vivid and characteristic, but as physical elucidations of the phenomena they are absolutely irrational.

In conclusion, it must be obvious to every one that the theoretical part of the Theory of Colour is not natural philosophy at all; at the same time we can, to a certain extent, see that the poet wanted to introduce a totally different method into the study of Nature, and more or less understand how he came to do so. Poetry is concerned solely with the 'beautiful show' which makes it possible to contemplate the ideal; how that show is produced is a matter of indifference. Even nature is, in the poet's eyes, but the sensible expression of the spiritual. The natural philosopher, on the other hand, tries to discover the levers, the cords, and the pulleys which work behind the scenes, and shift them. Of course the sight of the machinery spoils the beautiful show, and therefore the poet would gladly talk it out of existence, and ignoring cords and pulleys as the chimeras of a pedant's brain, he would have us believe that the scenes shift themselves, or are governed by the idea of the drama. And it is just characteristic of Goethe that he, and he alone among poets, must needs break a lance with natural philosophers. Other poets are either so entirely carried away by the fire of their enthusiasm that they do not trouble themselves about the disturbing influences of the outer world, or else they rejoice in the triumphs of mind over matter, even on that unpropitious battlefield. But Goethe, whom no intensity of subjective feeling could blind to the realities around him, cannot rest satisfied until he has stamped reality itself with the image and superscription of poetry. This constitutes the peculiar beauty of his poetry, and at the same time fully accounts for his resolute

hostility to the machinery that every moment threatens to disturb his poetic repose, and for his determination to attack the enemy in his own camp.

But we cannot triumph over the machinery of matter by ignoring it; we can triumph over it only by subordinating it to the aims of our moral intelligence. We must familiarise ourselves with its levers and pulleys, fatal though it be to poetic contemplation, in order to be able to govern them after our own will, and therein lies the complete justification of physical investigation, and its vast importance for the advance of human civilisation.

From what I have said it will be apparent that Goethe did follow the same line of thought in all his contributions to science, but that the problems he encountered were of diametrically opposite characters. And, perhaps, when it is understood how the self-same characteristic of his intellect, which in one branch of science won for him immortal renown, entailed upon him egregious failure in the other, it will tend to dissipate, in the minds of many worshippers of the great poet, a lingering prejudice against natural philosophers, whom they suspect of being blinded by narrow professional pride to the loftiest inspirations of genius.

ON THE
PHYSIOLOGICAL CAUSES OF HARMONY
IN MUSIC.

A Lecture delivered in Bonn during the Winter of 1857.

LADIES AND GENTLEMEN,—In the native town of Beethoven, the mightiest among the heroes of harmony, no subject seemed to me better adapted for a popular audience than music itself. Following, therefore, the direction of my researches during the last few years, I will endeavour to explain to you what physics and physiology have to say regarding the most cherished art of the Rhenish land—music and musical relations. Music has hitherto withdrawn itself from scientific treatment more than any other art. Poetry, painting, and sculpture borrow at least the material for their delineations from the world of experience. They portray nature and man. Not only can their material be critically investigated in respect to its correctness and truth to nature, but scientific art-criticism, however much enthusiasts may have disputed its right to do so, has actually succeeded in making some progress in investigating the causes of that æsthetic pleasure which it is the intention of these arts to excite. In music, on the other hand, it seems at first sight as if those were still in the right who reject all ‘anatomisation of pleasurable sensations.’ This art, borrowing no part of its material from the experience of our senses, not attempting to describe, and

only exceptionally to imitate the outer world, necessarily withdraws from scientific consideration the chief points of attack which other arts present, and hence seems to be as incomprehensible and wonderful as it is certainly powerful in its effects. We are, therefore, obliged, and we purpose, to confine ourselves, in the first place, to a consideration of the material of the art, musical sounds or sensations. It always struck me as a wonderful and peculiarly interesting mystery, that in the theory of musical sounds, in the physical and technical foundations of music, which above all other arts seems in its action on the mind as the most immaterial, evanescent, and tender creator of incalculable and indescribable states of consciousness, that here in especial the science of purest and strictest thought—mathematics—should prove pre-eminently fertile. Thorough bass is a kind of applied mathematics. In considering musical intervals, divisions of time, and so forth, numerical fractions, and sometimes even logarithms, play a prominent part. Mathematics and music! the most glaring possible opposites of human thought! and yet connected, mutually sustained! It is as if they would demonstrate the hidden consensus of all the actions of our mind, which in the revelations of genius makes us forefeel unconscious utterances of a mysteriously active intelligence.

When I considered physical acoustics from a physiological point of view, and thus more closely followed up the part which the ear plays in the perception of musical sounds, much became clear of which the connection had not been previously evident. I will attempt to inspire you with some of the interest which these questions have awakened in my own mind, by endeavouring to exhibit a few of the results of physical and physiological acoustics.

The short space of time at my disposal obliges me to confine my attention to one particular point; but I shall select the most important of all, which will best show you the significance and results of scientific investigation in this field; I mean the foundation of concord. It is an acknowledged fact that the numbers of the vibrations of concordant tones bear to each

other ratios expressible by small whole numbers. But why? What have the ratios of small whole numbers to do with concord? This is an old riddle, propounded by Pythagoras, and hitherto unsolved. Let us see whether the means at the command of modern science will furnish the answer.

First of all, what is a musical tone? Common experience teaches us that all sounding bodies are in a state of vibration. This vibration can be seen and felt; and in the case of loud sounds we feel the trembling of the air even without touching the sounding bodies. Physical science has ascertained that any series of impulses which produce a vibration of the air will, if repeated with sufficient rapidity, generate sound.

This sound becomes a *musical* tone, when such rapid impulses recur with perfect regularity and in precisely equal times. Irregular agitation of the air generates only noise. The *pitch* of a musical tone depends on the number of impulses which take place in a given time; the more there are in the same time the higher or sharper is the tone. And, as before remarked, there is found to be a close relationship between the well-known harmonious musical intervals and the number of the vibrations of the air. If twice as many vibrations are performed in the same time for one tone as for another, the first is the octave above the second. If the numbers of vibrations in the same time are as 2 to 3, the two tones form a fifth; if they are as 4 to 5, the two tones form a major third.

If you observe that the numbers of the vibrations which generate the tones of the major chord C E G c are in the ratio of the numbers 4 : 5 : 6 : 8, you can deduce from these all other relations of musical tones, by imagining a new major chord, having the same relations of the numbers of vibrations, to be formed upon each of the above-named tones. The numbers of vibrations within the limits of audible tones which would be obtained by executing the calculation thus indicated are extraordinarily different. Since the octave above any tone has twice as many vibrations as the tone itself, the second octave above will have four times, the third has eight times as many. Our modern pianofortes have seven octaves. Their highest

tones, therefore, perform 128 vibrations in the time that their lowest tone makes one single vibration.

The deepest C_1 which our pianos usually possess answers to the sixteen-foot open pipe of the organ—musicians call it the ‘contra-C’—and makes thirty-three vibrations in one second of time. This is very nearly the limit of audibility. You will have observed that these tones have a dull, bad quality of sound on the piano, and that it is difficult to determine their pitch and the accuracy of their tuning. On the organ the contra-C is somewhat more powerful than on the piano, but even here some uncertainty is felt in judging of its pitch. On larger organs there is a whole octave of tones below the contra-C, reaching to the next lower C, with $16\frac{1}{2}$ vibrations in a second. But the ear can scarcely separate these tones from an obscure drone; and the deeper they are the more plainly can it distinguish the separate impulses of the air to which they are due. Hence they are used solely in conjunction with the next higher octaves, to strengthen their notes, and produce an impression of greater depth.

With the exception of the organ, all musical instruments, however diverse the methods in which their sounds are produced, have their limit of depth at about the same point in the scale as the piano; not because it would be impossible to produce slower impulses of the air of sufficient power, but because the ear refuses its office, and hears slower impulses separately, without gathering them up into single tones.

The often-repeated assertion of the French physicist Savart, that he heard tones of eight vibrations in a second, upon a peculiarly constructed instrument, seems due to an error.

Ascending the scale from the contra-C, pianofortes usually have a compass of seven octaves, up to the so-called five-accented c , which has 4,224 vibrations in a second. Among orchestral instruments it is only the piccolo flute which can reach as high, and this will give even one tone higher. The violin usually mounts no higher than the e below, which has 2,640 vibrations—of course we except the gymnastics of heaven-scaling *virtuosi*, who are ever striving to excruciate their audience by some new

impossibility. Such performers may aspire to three whole octaves lying above the five-accented c , and very painful to the ear, for their existence has been established by Despretz, who, by exciting small tuning-forks with a violin bow, obtained and heard the eight-accented c , having 32,770 vibrations in a second. Here the sensation of tone seemed to have reached its upper limit, and the intervals were really undistinguishable in the later octaves.

The musical pitch of a tone depends entirely on the number of vibrations of the air in a second, and not at all upon the mode in which they are produced. It is quite indifferent whether they are generated by the vibrating strings of a piano or violin, the vocal chords of the human larynx, the metal tongues of the harmonium, the reeds of the clarionet, oboe, and bassoon, the trembling lips of the trumpeter, or the air cut by a sharp edge in organ pipes and flutes.

A tone of the same number of vibrations has always the same pitch, by whichever one of these instruments it is produced. That which distinguishes the note A of a piano, for example, from the equally high A of the violin, flute, clarionet, or trumpet, is called the *quality of the tone*, and to this we shall have to recur presently.

As an interesting example of these assertions, I beg to show you a peculiar physical instrument for producing musical tones, called the *siren*, Fig. 1, which is especially adapted to establish the properties resulting from the ratios of the numbers of vibrations.

In order to produce tones upon this instrument, the portvents g_0 and g_1 are connected by means of flexible tubes with a bellows. The air enters into round brass boxes, a_0 and a_1 , and escapes by the perforated covers of these boxes at c_0 and c_1 . But the holes for the escape of air are not perfectly free. Immediately before the covers of both boxes there are two other perforated discs, fastened to a perpendicular axis k , which turns with great readiness. In the figure, only the perforated disc can be seen at c_0 , and immediately below it is the similarly perforated cover of the box. In the upper box, c_1 , only the edge of the disc is visible. If then the holes of the disc are precisely opposite to those of the cover, the air can escape freely. But if the disc is made to revolve, so that some of its unperforated

FIG. 1.

portions stand before the holes of the box, the air cannot escape at all. On turning the disc rapidly, the vent-holes of the box are alternately opened and closed. During the opening, air escapes; during the closure, no air can pass. Hence the continuous stream of air from the bellows is converted into a series of discontinuous puffs, which, when they follow one another with sufficient rapidity, gather themselves together into a tone.

Each of the revolving discs of this instrument (which is more complicated in its construction than any one of the kind hitherto made, and hence admits of a much greater number of combinations of tone) has four concentric circles of holes, the lower set having 8, 10, 12, 18, and the upper set 9, 12, 15, and 16 holes respectively. The series of holes in the covers of the boxes are precisely the same as those in the discs, but under each of them lies a perforated ring, which can be so arranged, by means of the stops *iiii*, that the corresponding holes of the cover can either communicate freely with the inside of the box, or are entirely cut off from it. We are thus enabled to use any one of the eight series of holes singly, or combined two and two, or three and three together, in any arbitrary manner.

The round boxes, $h_0 h_0$ and $h_1 h_1$, of which halves only are drawn in the figure, serve by their resonance to soften the harshness of the tone.

The holes in the boxes and discs are cut obliquely, so that when the air enters the boxes through one or more of the series of holes, the wind itself drives the discs round with a perpetually increasing velocity.

On beginning to blow the instrument, we first hear separate impulses of the air, escaping as puffs, as often as the holes of the disc pass in front of those of the box. These puffs of air follow one another more and more quickly, as the velocity of the revolving discs increases, just like the puffs of steam of a locomotive on beginning to move with the train. They next produce a whirring and whizzing, which constantly becomes more rapid. At last we hear a dull drone, which, as the velocity further increases, gradually gains in pitch and strength.

Suppose that the discs have been brought to a velocity of 33 revolutions in a second, and that the series with 8 holes has been opened. At each revolution of the disc all these 8 holes will pass before each separate hole of the cover. Hence there will be 8 puffs for each revolution of the disc, or 8 times 33, that is, 264 puffs in a

second. This gives us the once-accented c' of our musical scale [that is, 'middle c ,' written on the leger line between the bass and treble staves]. But on opening the series of 16 holes instead, we have twice as many, or 16 times 33, that is, 528 vibrations in a second. We hear exactly the octave above the first c' , that is, the twice-accented c'' [or c on the third space of the treble staff]. By opening both the series of 8 and 16 holes at once, we have both c' and c'' at once, and can convince ourselves that we have the absolutely pure concord of the octave. By taking 8 and 12 holes, which give numbers of vibrations in the ratio of 2 to 3, we have the concord of a perfect fifth. Similarly 12 and 16 or 9 and 12 give fourths, 12 and 15 give a major third, and so on.

The upper box is furnished with a contrivance for slightly sharpening or flattening the tones which it produces. This box is movable upon an axis, and connected with a toothed wheel, which is worked by the driver attached to the handle d . By turning the handle slowly while one of the series of holes in the upper box is in use, the tone will be sharper or flatter, according as the box moves in the opposite direction to the disc, or in the same direction as the disc. When the motion is in the opposite direction, the holes meet those of the disc a little sooner than they otherwise would, the time of vibration of the tone is shortened, and the tone becomes sharper. The contrary ensues in the other case.

Now, on blowing through 8 holes below and 16 above, we have a perfect octave, as long as the upper box is still; but when it is in motion, the pitch of the upper tone is slightly altered, and the octave becomes false.

On blowing through 12 holes above and 18 below, the result is a perfect fifth as long as the upper box is at rest, but if it moves the concord is perceptibly injured.

These experiments with the siren show us, therefore:—

1. That a series of puffs following one another with sufficient rapidity produce a musical tone.

2. That the more rapidly they follow one another, the sharper is the tone.

3. That when the ratio of the number of vibrations is exactly 1 to 2, the result is a perfect octave; when it is 2 to 3, a perfect fifth; when it is 3 to 4, a pure fourth, and so on. The slightest alteration in these ratios destroys the purity of the concord.

You will perceive, from what has been hitherto adduced,

that the human ear is affected by vibrations of the air, within certain degrees of rapidity—viz. from about 20 to about 32,000 in a second—and that the sensation of musical tone arises from this affection.

That the sensation thus excited is a sensation of musical tone does not depend in any way upon the peculiar manner in which the air is agitated, but solely on the peculiar powers of sensation possessed by our ears and auditory nerves. I remarked, a little while ago, that when the tones are loud the agitation of the air is perceptible to the skin. In this way deaf mutes can perceive the motion of the air which we call sound. But they do not hear, that is, they have no sensation of tone in the ear. They feel the motion by the nerves of the skin, producing that peculiar description of sensation called whirring. The limits of the rapidity of vibration within which the ear feels an agitation of the air to be sound, depend also wholly upon the peculiar constitution of the ear.

When the siren is turned slowly, and hence the puffs of air succeed each other slowly, you hear no musical sound. By the continually increasing rapidity of its revolution, no essential change is produced in the kind of vibration of the air. Nothing new happens externally to the ear. The only new result is the sensation experienced by the ear, which then for the first time begins to be affected by the agitation of the air. Hence the more rapid vibrations receive a new name, and are called Sound. If you admire paradoxes, you may say that aërial vibrations do not become sound until they fall upon a hearing ear.

I must now describe the propagation of sound through the atmosphere. The motion of a mass of air through which a tone passes belongs to the so-called wave-motions—a class of motions of great importance in physics. Light, as well as sound, is one of these motions.

The name is derived from the analogy of waves on the surface of water, and these will best illustrate the peculiarity of this description of motion.

When a point in a surface of still water is agitated—as by throwing in a stone—the motion thus caused is propagated in

the form of waves, which spread in rings over the surface of the water. The circles of waves continue to increase even after rest has been restored at the point first affected. At the same time the waves become continually lower, the further they are removed from the centre of motion, and gradually disappear. On each wave-ring we distinguish ridges or crests, and hollows or troughs.

Crest and trough together form a wave, and we measure its length from one crest to the next.

While the wave passes over the surface of the fluid, the particles of the water which form it do not move on with it. This is easily seen, by floating a chip of straw on the water. When the waves reach the chip, they raise or depress it, but when they have passed over it the position of the chip is not perceptibly changed.

Now a light floating chip has no motion different from that of the adjacent particles of water. Hence we conclude that these particles do not follow the wave, but, after some pitching up and down, remain in their original position. That which really advances as a wave is, consequently, not the particles of water themselves, but only a superficial form, which continues to be built up by fresh particles of water. The paths of the separate particles of water are more nearly vertical circles, in which they revolve with a tolerably uniform velocity, as long as the waves pass over them.

In Fig. 2 the dark wave-line A B C represents a section of the surface of the water over which waves are running in the direction of the arrows above a and c. The three circles a, b, and c represent the paths of particular particles of water at the surface of the wave. The particle which revolves in the circle b is supposed, at the time that the surface of the water presents the form A B C, to be at its highest point B, and the particles revolving in the circles a and c to be simultaneously in their lowest positions.

The respective particles of water revolve in these circles in the direction marked by the arrows. The dotted curves represent other positions of the passing waves, at equal intervals of time, partly before the assumption of the A B C position (as for the crests between a and b), and partly after the same (for the crests between b

and c). The positions of the crests are marked with figures. The same figures in the three circles show where the respective revolving particle would be, at the moment the wave assumed the corresponding form. It will be noticed that the particles advance by equal arcs of the circles, as the crest of the wave advances by equal distances parallel to the water level.

In the circle b it will be further seen that the particle of water in its positions 1, 2, 3 hastens to meet the approaching wave-crests, 1, 2, 3, rises on its left-hand side, is then carried on by the crest from 4 to 7 in the direction of its advance, afterwards halts behind it, sinks down again on the right side, and finally reaches its original position at 13. (In the Lecture itself, Fig. 2 was replaced by a working model, in which the movable particles, connected by threads, really revolved in circles, while connecting elastic threads represented the surface of the water.)

FIG. 2.

All particles at the surface of the water, as you see by this drawing, describe equal circles. The particles of water at different depths move in the same way, but as the depths increase, the diameters of their circles of revolution rapidly diminish.

In this way, then, arises the appearance of a progressive motion along the surface of the water, while in reality the moving particles of water do not advance with the wave, but perpetually revolve in their small circular orbits.

To return from waves of water to waves of sound. Imagine an elastic fluid like air to replace the water, and the waves of this replaced water to be compressed by an inflexible plate laid on their surface, the fluid being prevented from escaping laterally from the pressure. Then on the waves being thus flattened out, the ridges where the fluid had been heaped up

will produce much greater density than the hollows, from which the fluid had been removed to form the ridges. Hence the ridges are replaced by condensed strata of air, and the hollows by rarefied strata. Now further imagine that these compressed waves are propagated by the same law as before, and that also the vertical circular orbits of the several particles of water are compressed into horizontal straight lines. Then the waves of sound will retain the peculiarity of having the particles of air only oscillating backwards and forwards in a straight line, while the wave itself remains merely a progressive form of motion, continually composed of fresh particles of air. The immediate result then would be waves of sound spreading out horizontally from their origin.

But the expansion of waves of sound is not limited, like those of water, to a horizontal surface. They can spread out in any direction whatsoever. Suppose the circles generated by a stone thrown into the water to extend in all directions of space, and you will have the spherical waves of air by which sound is propagated.

Hence we can continue to illustrate the peculiarities of the motion of sound by the well-known visible motions of waves of water.

The length of a wave of water, measured from crest to crest, is extremely different. A falling drop, or a breath of air, gently curls the surface of the water. The waves in the wake of a steamboat toss the swimmer or skiff severely. But the waves of a stormy ocean can find room in their hollows for the keel of a ship of the line, and their ridges can scarcely be overlooked from the mast-head. The waves of sound present similar differences. The little curls of water with short lengths of wave correspond to high tones, the giant ocean billows to deep tones. Thus the contrabass C has a wave thirty-five feet long, its higher octave a wave of half the length, while the highest tones of a piano have waves of only three inches in length.

¹ The exact lengths of waves corresponding to certain *notes*, or symbols of tone, depend upon the standard pitch assigned to one particular note, and

You perceive that the pitch of the tone corresponds to the length of the wave. To this we should add that the height of the ridges, or, transferred to air, the degree of alternate condensation and rarefaction, corresponds to the loudness and intensity of the tone. But waves of the same height may have different forms. The crest of the ridge, for example, may be rounded off or pointed. Corresponding varieties also occur in waves of sound of the same pitch and loudness. The so-called *timbre* or quality of tone is what corresponds to the *form* of the waves of water. The conception of form is transferred from waves of water to waves of sound. Supposing waves of water of *different* forms to be pressed flat as before, the surface, having been levelled, will of course display no differences of form, but, in the interior of the mass of water, we shall have different distributions of pressure, and hence of density, which exactly correspond to the differences of form in the still uncompressed surface. In this sense then we can continue to speak of

FIG. 3.

the form of waves of sound, and can represent it geometrically. We make the curve rise where the pressure, and hence density, increases, and fall where it diminishes—just as if we had a compressed fluid beneath the curve, which would expand to the height of the curve in order to regain its natural density.

Unfortunately, the form of waves of sound, on which depends the quality of the tones produced by various sounding bodies, can at present be assigned in only a very few cases.

Among the forms of waves of sound which we are able to determine with more exactness is one of great importance, here termed the *simple* or *pure* wave-form, and represented in Fig. 3.

this differs in different countries. Hence the figures of the author have been left unreduced. They are sufficiently near to those usually adopted in England, to occasion no difficulty to the reader in these general remarks.—TR

It can be seen in waves of water only when their height is small in comparison with their length, and they run over a smooth surface without external disturbance, or without any action of wind. Ridge and hollow are gently rounded off, equally broad and symmetrical, so that, if we inverted the curve, the ridges would exactly fit into the hollows, and conversely. This form of wave would be more precisely defined by saying

FIG. 4.

that the particles of water describe exactly circular orbits of small diameters, with exactly uniform velocities. To this simple wave-form corresponds a peculiar species of tone, which, from reasons to be hereafter assigned, depending upon its relation to quality, we will term a *simple* tone. Such tones are produced by striking a tuning-fork and holding it before the opening of a properly tuned resonance tube. The tone of tuneful human

voices, singing the vowel *oo* in *too*, in the middle positions of their register, appears not to differ materially from this form of wave.

We also know the laws of the motion of strings with sufficient accuracy to assign in some cases the form of motion which they impart to the air. Thus Fig. 4 represents the forms successively assumed by a string struck, as in the German *Zither*, by a pointed style [the *plectrum* of the ancient *lyra*, or the quill of the old harpsichord, which may be easily imitated on a guitar]. A a represents the form assumed by the string at the moment of percussion. Then, at equal intervals of time, follow the forms B, C, D, E, F, G; and then, in inverse order, F, E, D, C, B, A, and so on in perpetual repetition. The form of motion which such a string, by means of an attached sounding-board, imparts to the surrounding air, probably corresponds to the broken line in Fig. 5, where h h indicates the position of equilibrium, and the letters a b c d e f g show the line of the wave which is produced by the action of several forms of string marked by the corresponding capital letters in Fig. 4. It is easily seen how greatly this form of wave (which of course

FIG. 5.

could not occur in water) differs from that of Fig. 3 (independently of magnitude), as the string only imparts to the air a series of short impulses, alternately directed to opposite sides.¹

The waves of air produced by the tone of a violin would, on

FIG. 6.

the same principle, be represented by Fig. 6. During each

¹ It is here assumed that the sounding-board and air in contact with it immediately obey the impulse given by the end of the string without exercising a perceptible reaction on the motion of the string.

period of vibration the pressure increases uniformly, and at the end falls back suddenly to its minimum.

It is to such differences in the forms of the waves of sound that the variety of quality in musical tones is due. We may even carry the analogy further. The more uniformly rounded the form of wave, the softer and milder is the quality of tone. The more jerking and angular the wave-form, the more piercing the quality. Tuning-forks, with their rounded forms of wave (Fig. 3), have an extraordinarily soft quality; and the qualities of tone generated by the zither and violin resemble in harshness the angularity of their wave-forms. (Figs. 5 and 6.)

Finally, I would direct your attention to an instructive spectacle, which I have never been able to view without a certain degree of physico-scientific delight, because it displays to the bodily eye, on the surface of water, what otherwise could only be recognised by the mind's eye of the mathematical thinker in a mass of air traversed in all directions by waves of sound. I allude to the composition of many different systems of waves, as they pass over one another, each undisturbedly pursuing its own path. We can watch it from the parapet of any bridge spanning a river, but it is most complete and sublime when viewed from a cliff beside the sea. It is then rare not to see innumerable systems of waves, of various length, propagated in various directions. The longest come from the deep sea and dash against the shore. Where the boiling breakers burst shorter waves arise, and run back again towards the sea. Perhaps a bird of prey darting after a fish gives rise to a system of circular waves, which, rocking over the undulating surface, are propagated with the same regularity as on the mirror of an inland lake. And thus, from the distant horizon, where white lines of foam on the steel blue surface betray the coming trains of wave, down to the sand beneath our feet, where the impression of their arcs remains, there is unfolded before our eyes a sublime image of immeasurable power and unceasing variety, which, as the eye at once recognises its pervading order and law, enchains and exalts without confusing the mind.

Now, just in the same way you must conceive the air of a

concert-hall or ball-room traversed in every direction, and not merely on the surface, by a variegated crowd of intersecting wave-systems. From the mouths of the male singers proceed waves of six to twelve feet in length; from the lips of the song-stresses dart shorter waves, from eighteen to thirty-six inches long. The rustling of silken skirts excites little curls in the air, each instrument in the orchestra emits its peculiar waves, and all these systems expand spherically from their respective centres, dart through each other, are reflected from the walls of the room, and thus rush backwards and forwards, until they succumb to the greater force of newly generated tones.

Although this spectacle is veiled from the material eye, we have another bodily organ, the ear, specially adapted to reveal it to us. This analyses the interdigitation of the waves, which in such cases would be far more confused than the intersection of the water undulations, separates the several tones which compose it, and distinguishes the voices of men and women—nay, even of individuals—the peculiar qualities of tone given out by each instrument, the rustling of the dresses, the footfalls of the walkers, and so on.

It is necessary to examine the circumstances with greater minuteness. When a bird of prey dips into the sea, rings of waves arise, which are propagated as slowly and regularly upon the moving surface as upon a surface at rest. These rings are cut into the curved surface of the waves in precisely the same way as they would have been into the still surface of a lake. The form of the external surface of the water is determined in this, as in other more complicated cases, by taking the height of each point to be the height of all the ridges of the waves which coincide at this point at one time, after deducting the sum of all similarly simultaneously coincident hollows. Such a sum of positive magnitudes (the ridges) and negative magnitudes (the hollows), where the latter have to be subtracted instead of being added, is called an *algebraical sum*. Using this term, then, we may say that *the height of every point of the surface of the water is equal to the algebraical sum of all the portions of the waves which at that moment there concur.*

It is the same with the waves of sound. They, too, are added together at every point of the mass of air, as well as in contact with the listener's ear. For them also the degree of condensation and the velocity of the particles of air in the passages of the organ of hearing are equal to the algebraical sums of the separate degrees of condensation and of the velocities of the waves of sound, considered apart. This single motion of the air produced by the simultaneous action of various sounding bodies, has now to be analysed by the air into the separate parts which correspond to their separate effects. For doing this the ear is much more unfavourably situated than the eye. The latter surveys the whole undulating surface at a glance. But the ear can, of course, only perceive the motion of the particles of air which impinge upon it. And yet the ear solves its problem with the greatest exactness, certainty, and determinacy. This power of the ear is of supreme importance for hearing. Were it not present it would be impossible to distinguish different tones.

Some recent anatomical discoveries appear to give a clue to the explanation of this important power of the ear.

You will all have observed the phenomena of the sympathetic production of tones in musical instruments, especially stringed instruments. The string of a pianoforte when the damper is raised begins to vibrate as soon as its proper tone is produced in its neighbourhood with sufficient force by some other means. When this foreign tone ceases the tone of the string will be heard to continue some little time longer. If we put little paper riders on the string they will be jerked off when its tone is thus produced in the neighbourhood. This sympathetic action of the string depends on the impact of the vibrating particles of air against the string and its sounding-board.

Each *separate* wave-crest (or condensation) of air which passes by the string is, of course, too weak to produce a sensible motion in it. But when a long series of wave-crests (or condensations) strike the string in such a manner that each succeeding one increases the slight tremor which resulted from the action of its predecessors, the effect finally becomes sensible. It is a process of exactly the same nature as the swinging of a

heavy bell. A powerful man can scarcely move it sensibly by a single impulse. A boy, by pulling the rope at regular intervals corresponding to the time of its oscillations, can gradually bring it into violent motion.

This peculiar reinforcement of vibration depends entirely on the rhythmical application of the impulse. When the bell has been once made to vibrate as a pendulum in a very small arc, and the boy always pulls the rope as it falls, and at a time that his pull augments the existing velocity of the bell, this velocity, increasing slightly at each pull, will gradually become considerable. But if the boy apply his power at irregular intervals, sometimes increasing and sometimes diminishing the motion of the bell, he will produce no sensible effect.

In the same way that a mere boy is thus enabled to swing a heavy bell, the tremors of light and mobile air suffice to set in motion the heavy and solid mass of steel contained in a tuning-fork, provided that the tone which is excited in the air is exactly in unison with that of the fork, because in this case also every impact of a wave of air against the fork increases the motions excited by the like previous blows.

This experiment is most conveniently performed on a fork, Fig. 7, which is fastened to a sounding-board, the air being excited by a similar fork of precisely the same pitch. If one is struck, the other will be found after a few seconds to be sounding also. Then damp the first fork, by touching it for a moment with a finger, and the second will continue the tone. The second will then bring the first into vibration, and so on.

But if a very small piece of wax be attached to the ends of one of the forks, whereby its pitch will be rendered scarcely perceptibly lower than the other, the sympathetic vibration of the second fork ceases, because the times of oscillation are no longer the same in each. The blows which the waves of air excited by the first inflict upon the sounding-board of the second fork, are indeed for a time in the same direction as the motions of the second fork, and consequently increase the latter, but after a very short time they cease to be so, and consequently destroy the slight motion which they had previously excited.

Lighter and more mobile elastic bodies, as for example strings, can be set in motion by a much smaller number of aërial impulses. Hence they can be set in sympathetic motion much more easily than tuning-forks, and by means of a musical tone which is far less accurately in unison with themselves.

Now, then, if several tones are sounded in the neighbourhood of a pianoforte, no string can be set in sympathetic vibration unless it is in unison with one of those tones. For example, depress the forte pedal (thus raising the dampers), and put paper riders on all the strings. They will of course leap

FIG. 7.

off when their strings are put in vibration. Then let several voices or instruments sound tones in the neighbourhood. All those riders, and *only* those, will leap off which are placed upon strings that correspond to tones of the same pitch as those sounded. You perceive that a pianoforte is also capable of analysing the wave confusion of the air into its elementary constituents.

The process which actually goes on in our ear is probably very like that just described. Deep in the petrous bone out of which the internal ear is hollowed lies a peculiar organ, the cochlea or snail shell—a cavity filled with water, and so called

from its resemblance to the shell of a common garden snail. This spiral passage is divided throughout its length into three sections, upper, middle, and lower, by two membranes stretched in the middle of its height. The Marchese Corti discovered some very remarkable formations in the middle section. They

FIG. 8.

consist of innumerable plates, microscopically small, and arranged orderly side by side, like the keys of a piano. They are connected at one end with the fibres of the auditory nerve, and at the other with the stretched membrane.

Fig. 8 shows this extraordinarily complicated arrangement

for a small part of the partition of the cochlea. The arches which leave the membrane at d and are reinserted at e, reaching their greatest height between m and o, are probably the parts which are suited for vibration. They are spun round with innumerable fibrils, among which some nerve fibres can be recognised, coming to them through the holes near c. The transverse fibres g, h, i, k, and the cells o, also appear to belong to the nervous system. There are about three thousand arches similar to d e, lying orderly beside each other, like the keys of a piano in the whole length of the partition of the cochlea.

In the so-called vestibulum, also, where the nerves expand upon little membranous bags swimming in water, elastic appendages, similar to stiff hairs, have been lately discovered at the ends of the nerves. The anatomical arrangement of these appendages leaves scarcely any room to doubt that they are set into sympathetic vibration by the waves of sound which are conducted through the ear. Now if we venture to conjecture—it is at present only a conjecture, but after careful consideration I am led to think it very probable—that every such appendage is tuned to a certain tone like the strings of a piano, then the recent experiment with a piano shows you that when (and only when) that tone is sounded the corresponding hair-like appendage may vibrate, and the corresponding nerve-fibre experience a sensation, so that the presence of each single such tone in the midst of a whole confusion of tones must be indicated by the corresponding sensation.

Experience then shows us that the ear really possesses the power of analysing waves of air into their elementary forms.

By compound motions of the air, we have hitherto meant such as have been caused by the simultaneous vibration of several elastic bodies. Now, since the forms of the waves of sound of different musical instruments are different, there is room to suppose that the kind of vibration excited in the passages of the ear by one such tone will be exactly the same as the kind of vibration which in another case is there excited by two or more instruments sounded together. If the ear analyses the motion into its elements in the latter case, it cannot well

avoid doing so in the former, where the tone is due to a single source. And this is found to be really the case.

I have previously mentioned the form of wave with gently rounded crests and hollows, and termed it simple or pure (p. 65). In reference to this form the French mathematician Fourier has established a celebrated and important theorem which may be translated from mathematical into ordinary language thus : *Any form of wave whatever can be compounded of a number of simple waves of different lengths.* The longest of these simple waves has the same length as that of the given form of wave, the others have lengths one half, one third, one fourth, &c., as great.

By the different modes of uniting the crests and hollows of these simple waves, an endless multiplicity of wave-forms may be produced.

FIG. 9.

For example, the wave-curves A and B, Fig. 9, represent waves of simple tones, B making twice as many vibrations as A in a second