raw beef-steak per day. It is perfectly tame, and wanders all over the grounds and through the house.

The chief causes of death amongst aviary birds are pneumonia, avian tuberculosis, constipation through over-eating, and anæmia. If any bird shows signs of either of the former it should at once be removed.

THE ORGANIC CELL

PART IV.—ITS METHODS OF DIVISION AND STATUS IN THE PROCESS OF HEREDITY

BY E. WYNSTONE-WATERS, F.R.S.EDIN., &c., *Late Senior Demonstrator of Anatomy at the Royal College of Surgeons, Edinburgh.*

Mitotic cell-division ensures the continuity of life, and maintenance of the species, by passing on from cell to cell a counterpart of the chromatin which was the determining factor in its own organisation.

Cell-division runs in cycles, with a continual loss of energy. Rejuvenescence only occurs after the addition of material derived from the nucleus of another cell. The operation which results in this admixture is called fertilisation, and is the essential factor of sexual reproduction. The result of the fresh admixture of nuclear material is twofold:—the energy of cell-division is restored, and two separate lines of descent become fused in one. The actual reason why this double process should take place is unknown. One school of thinkers, represented by Herbert Spencer and Hertwig, believe that protoplasm shows a strong tendency to pass into a state of very stable equilibrium, and that in order to render it more responsive the addition of fresh nuclear material is necessary.

It has been pointed out that the life-history of the Metazoan is a parallel to that of the Protozoan, for in both of them, after a series of cell-divisions, a period of senescence sets in, which can only be prevented by conjugation. After conjugation there is a period of rejuvenescence, in which the functions of cell-division and growth are fully restored.

In parthenogenesis, however, the egg develops without fertilisation, and from this fact it is extremely difficult to decide whether a tendency to senile decay, and the necessity for fertilisation, are necessary properties of living matter.

The other teaching may be termed the Variation Theory. According to this view fertilisation is necessary to the production of variations, on which the process of natural selection can operate.

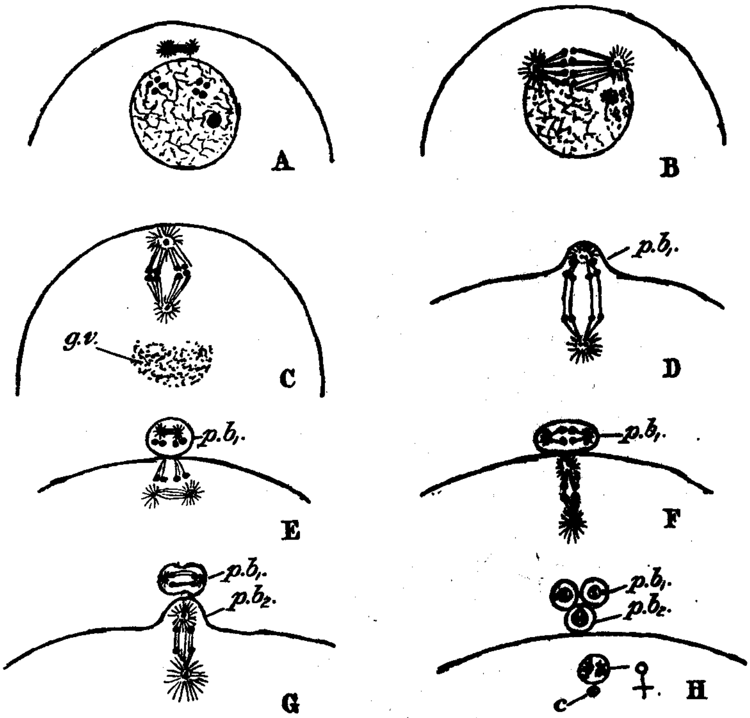
Both theories are in unison with the work of practical breeders, which shows that crossing results in greater vigour and variability.

As the time of fertilisation approaches, the nucleus of each cell contains its full supply of chromosomes ; it is therefore evident that if some of these bodies are not got rid of the number of chromosomes would be doubled during each generation. As a matter of fact, however, it has been proved beyond a doubt that during the period of maturation there is a reduction of the number of chromosomes to one half. It is also certain that this reduction of chromosomes in the male and female germ-cells is a process preparatory to their subsequent union. Thus, when the male and female cells unite, the normal number of chromosomes for the species is restored. It will now be necessary to examine very briefly this complicated process.

Reduction in the Female.

Each primordial germ-cell, by the usual mitotic type of division, gives rise to a number of cells called oogonia. These divide for a certain number of times, and then cease. Each develops into an ovarian ovum, the nucleus increasing very considerably in size to form the Germinal Vesicle, the cytoplasm becoming loaded with food material. The egg-cell remains in this state until the time of fertilisation approaches, when the process of chromatin reduction occurs. Two minute cells develop near the upper pole of the ovum, and as a rule one of these further divides into two. Thus a group of four cells arises, the mature egg and three small cells which are called polar bodies ; the polar bodies take no further part in development, but die. They must be regarded as merely rudimentary eggs, which have forfeited their right to live, for the common good of the permanent ovum.

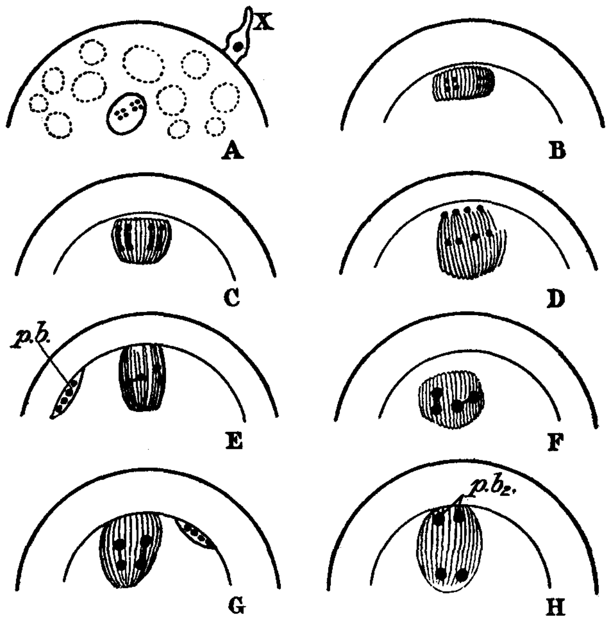
The case described below is that of *Ascaris*, the facts having been made out by Van Beneden and Boveri.



DIAGRAMS ILLUSTRATING THE MATURATION OF THE EGG. THE SOMATIC NUMBER OF CHROMOSOMES IS SUPPOSED TO BE FOUR.

A. Initial phase; two tetrads have been formed in the germinal vesicle B. The two tetrads have been drawn up about the spindle to form the equatorial plate of the first polar mitotic figure. C. The mitotic figure has rotated into position, leaving the remains of the germinal vesicle at *g.v.* D. Formation of the first polar body, each tetrad divides into two dyads. E. First polar body formed; two dyads in it, and two in the egg. F. Preparation for the second division. G. Second polar body forming, and the first dividing; each dyad divides into two single chromosomes. H. Final result; three polar bodies, and the egg-nucleus (♀), each containing two single chromosomes (half the somatic number); *c*. the egg-centrosome which now disappears.

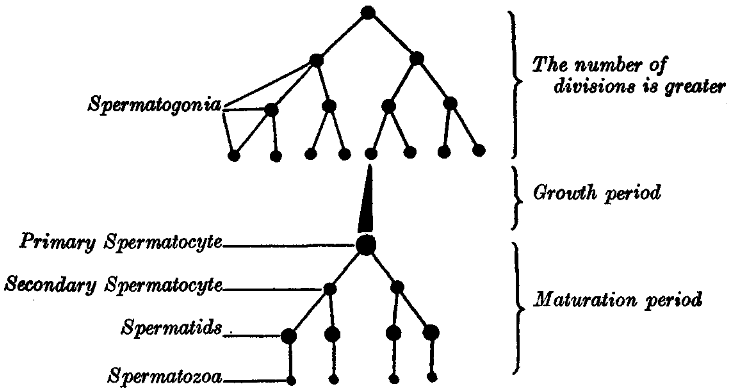
As the egg gets ready for the formation of the first polar body, the chromatin in the germinal vesicle (nucleus of ovum) arranges itself into masses, each mass divides into a group of four bodies which are connected by linin threads, forming what is known as a tetrad. The number of tetrads is always one half the usual number of chromosomes. In *Ascaris* two tetrads appear in the germinal vesicle, the normal number



FORMATION OF POLAR BODIES IN ASCARIS MEGALOCEPHALA VAR. BIVALENS. (Boveri.)

A. The egg, with sperm entering at X; the germinal vesicle contains two tetrads, the number of chromosomes in the species being four. B. First polar spindle. C. The tetrads dividing. D. First polar body formed, containing like the egg, two dyads. E, F. The dyads rotating into position for the second division, *p.b.* first polar body. G. The dyads dividing. H. Each dyad has divided into two single chromosomes, thus completing the reduction, the two at the periphery forming the second polar body $p.b_2$.

of chromosomes being four. During the formation of the first polar body, each tetrad becomes halved, to form two double groups or dyads; one group of dyads remains in the egg, the other joins the polar body. It is therefore evident that both the polar body and the egg receive a number of dyads equal to one half the usual number of chromosomes. The egg at once forms the second polar body, without any intervening reconstruction of the nucleus. Each dyad splits to form two single chromosomes, two single ones remaining in the egg, the other two going to the second polar body. According to this arrangement, both egg and second polar body each receive two single chromosomes, which is one half of the original number. The two remaining in the egg now form a nucleus.



THE GENESIS OF THE SPERMATOZOON. (Boveri.)

REDUCTION IN THE MALE.

Reduction in the male is a similar process to that maintaining in the female. In the same way as the ova the spermatozoa are descended from the primordial germ cells, which, undergoing mitosis, produce the spermatogonia. In the same manner as the oogonia, the spermatogonia continue to divide for a time, possessing the full number of chromosomes, *i.e.* four in *Ascaris*. The process of division is arrested for a time, and the spermatogonia enlarge to form spermatocytes. Each spermatocyte divides twice in rapid succession, the first division producing two daughter spermatocytes, the second division four spermatids, each of which becomes a spermatozoon. The chromatin reduction occurs in an exactly similar manner as in the case of the ovum, each spermatozoon receiving one half the usual number of single chromosomes.

Weismann's Theory of Reduction.

The object of the process of reduction of the chromosomes in the germ-cells is to maintain the constant number characteristic of the species, for without such a reduction the number

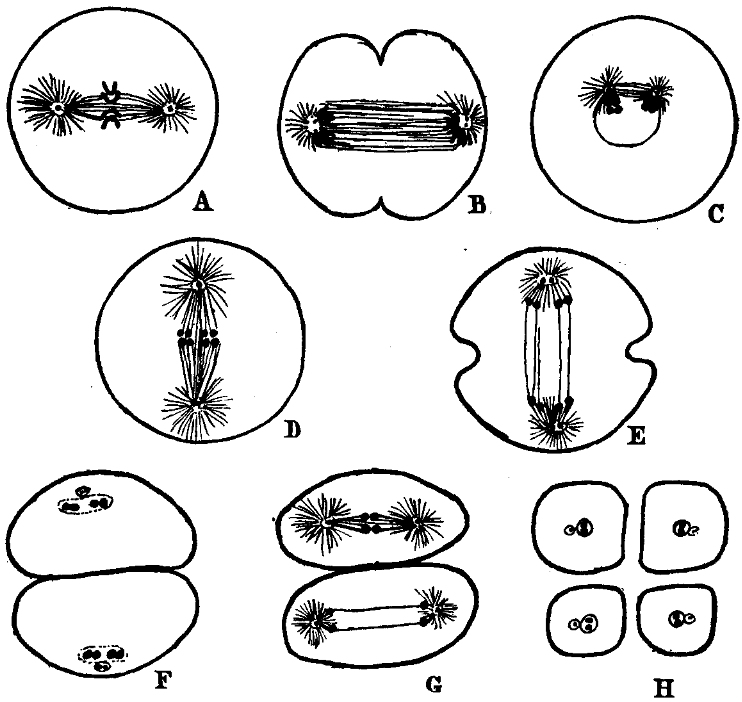


Diagram showing Reduction in the Male. Somatic Number of Chromosomes is supposed to be Four.

A, B. Division of one of the spermatogonia showing the full number (four) of chromosomes. C. Primary spermatocyte preparing for division; the chromatin forms two tetrads. D, E, F. First division to form two secondary spermatocytes, each of which receives two dyads. G, H. Division of the two secondary spermatocytes to form four spermatids. Each spermatid receives two single chromosomes and a centrosome which passes into the middle-piece of the spermatozoon.

would be doubled in each succeeding generation. Why should the number of chromosomes for a species be constant? Weismann's theory is based on a paper written by W. Roux in

1883. Roux argued that in order to understand and account for the complex process of mitosis it must be assumed that the chromatin differs in different regions, representing certain qualities in some, and others in other portions. He insisted that, if the chromatin was the same throughout, the process of direct division would be quite as effective as the very complicated process of karyokinesis, and this intricate method, by which there is an exact longitudinal splitting of the thread, would be a mere waste of energy.

Weismann's explanation of the process of fertilisation is that it brings about new mixtures of different 'ids.' The term 'id' used by him represents the visible chromatin granules, which are arranged in a linear series to form 'idants' or chromosomes.

The number of 'ids,' however, would be doubled by the union of two germ-nuclei; and should there not be a reduction of the chromatin prior to this union, in a few generations it would become exceedingly complicated. From his assumption that the ancestral germ-plasms (ids) are arranged in a linear series in the spireme thread, or the chromosomes derived from it, he prophesied that two kinds of mitosis would occur: the first a longitudinal division of the thread, which would bring about an equal distribution of the ancestral plasms to the daughter nuclei; the second form of division which he postulated was of such a character that each daughter-nucleus would receive half the number possessed by the mother-nucleus. He also assumed that this was brought about either by a transverse division of the chromosomes or by getting rid of complete chromosomes without division. Weismann, pursuing the subject still further, maintained that the reduction must be involved in the formation of the polar bodies, and in the similar phenomena occurring during spermatogenesis. Weismann's prophecy has been verified by the most rigid microscopical scrutiny. As Boveri has said: 'Thus, at some stage or other in the generation series of the germ-cells, there occurs a reduction of the number of chromosomes originally present to one half, and this numerical reduction is therefore to be regarded, not as a mere theoretical postulate, but as a fact.'

Fertilisation.

The egg of the sea-urchin is admirably adapted for watching the process of fusion between it and the sperm. The phenomenon occurring in sea-water, the germinal cells being cast out from the parents, one is able to collect eggs and spermatozoa separately, bringing them together in suitable vessels containing

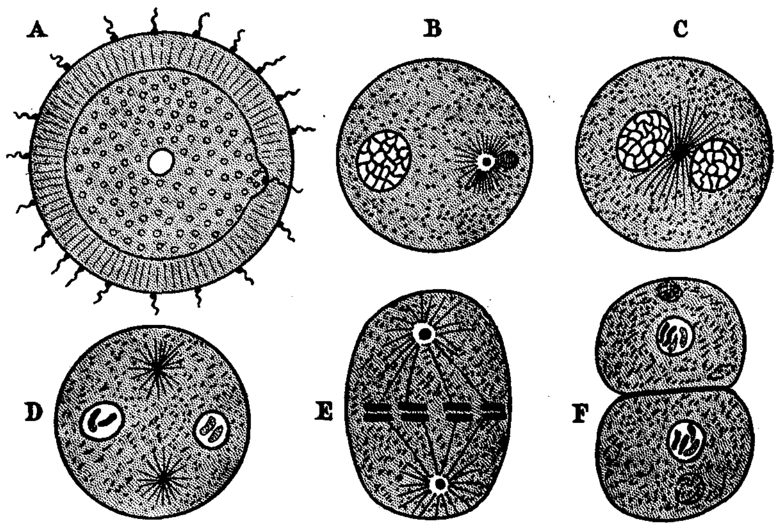


Diagram of the Fertilisation of the Egg. (After Boveri.)

A. Egg surrounded by spermatozoa; on the right one has penetrated the egg membrane, and is entering the cytoplasm. The egg nucleus is seen in the centre. B. Egg-nucleus, with chromatin reticulum on the left; on the right is seen the sperm-nucleus (head of spermatozoon) preceded by its centrosome and attraction sphere. C. Egg-nucleus on the left, sperm-nucleus on the right of the centre of egg. D. The centrosome has divided, the two attraction spheres separate to form the first cleavage-spindle. E. The first cleavage-spindles with splitting of the chromosomes. F. Completion of first cleavage, each nucleus contains four chromosomes, two from the egg, and two from the sperm.

N.B.—In the diagram the sperm-chromosomes are shaded; those from the egg-nucleus are black.

sea-water. The process can be watched under the microscope, and eggs killed at the various stages can be sectioned and mounted for future detailed examination. In the explanatory diagrams, which are after Boveri, A is the egg, surrounded by its envelope, and containing a clear nucleus. Around the periphery can be seen spermatozoa trying to get into the egg substance; at the right-hand side one has been more successful than the rest, having pierced the peripheral envelope, and is passing into the egg-cytoplasm. As soon as the head of one spermatozoon has entered, a new membrane forms around the egg substance which prevents the entrance of any more. There is evidence of a definite attraction between the germ-cells. The nature of the attraction appears to be chemical, since the spermatozoids of ferns are actively attracted by solutions of malic acid; those of mosses are not affected by malic acid, but by cane-sugar. This attractive force is not inherent in the nucleus alone, but is also present in the cytoplasm. The head and middle piece pass into the egg substance, the tail remaining in the egg membrane, where it degenerates. Very shortly after the entrance of the sperm, a series of radiations make their appearance around the middle piece, forming an aster surrounding a centrosome, B. The head of the spermatozoön or sperm nucleus swells, increasing to a considerable size, its chromatin becoming arranged to form a reticulum, C. At the same time the chromatin reticulum of the egg nucleus becomes more definite. Sperm aster and sperm nucleus now move toward the egg nucleus, the aster generally leading the way. On nearer approach the sperm nucleus increases still more in size, until it becomes indistinguishable from the egg nucleus C. The chromatin network of each nucleus now forms a number of chromosomes (one half the number in each nucleus as are found in the somatic cells). The nuclei come together and fuse.

In the sea-urchin *Echinus* the number of chromosomes is eighteen, nine being found in each germ nucleus. In the diagram, for the sake of simplicity, only two are shown, those of the sperm being shaded, while those of the egg nucleus are black.

The centrosome divides with its aster (D), the daughter centrosomes moving apart to the opposite poles of the egg, thus forming the usual amphiaster of cell-division (E); the chromosomes become arranged in the equatorial plane of the spindle, and each one divides longitudinally. The halves are now drawn apart by the astral rays towards the opposite poles, the egg dividing transversely into two cells (F). This phenomenon of division is repeated continuously, and from the resulting mass of cells is developed the new organism.

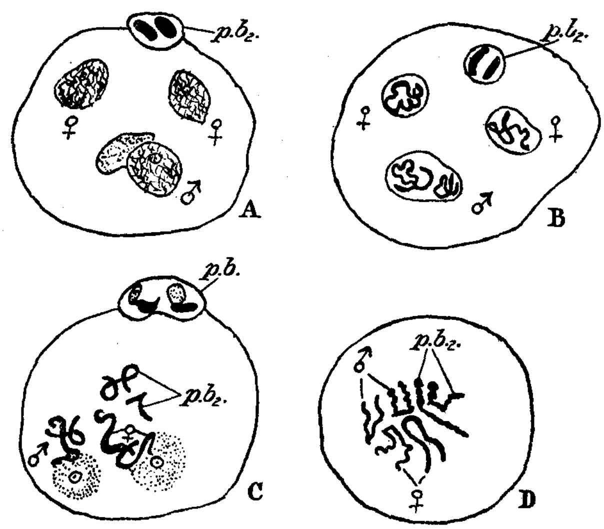
The centrosome, which must be regarded as the dynamic centre, the presence of which initiated these various changes, is derived solely from the spermatozoon, the egg on the other hand supplying the yolk and the bulk of the cytoplasm.

Individuality of the Chromosomes.

It is an established fact that a nucleus is never formed *de novo*, but must arise by the division of a pre-existing nucleus. In mitosis the chromatin is resolved into bodies called chromosomes, which have the power of growth and division, the same as the nucleus, forming in fact morphological individuals of a lower grade than the nucleus. This individual independence of the isolated chromosome has been strongly maintained by Rabl and Boveri. Rabl concluded that 'the chromosomes do not lose their individuality at the close of division, but persist in the chromatin reticulum of the resting nucleus. The so-called loss of identity during the resting stage is only apparent. At the commencement of the next division they again appear, the chromatic substance flowing back, through predetermined paths, into the primary chromosome-bodies.'

From many observations made, it would appear that, whatever be the number of chromosomes entering into the formation of a reticular nucleus, the same number always issues from it—this result proving that the number of chromosomes is due to the morphological organisation of the nucleus. Boveri confirmed this in echinoderms, by removing the nuclei from egg-fragments and fertilising these enucleated portions with single spermatozoa, the result being that the nuclei of such larvæ contain only half the normal number of chromosomes.

As further evidence, Van Beneden and Boveri showed clearly in *Ascaris* that during the development of the spireme the chromosomes actually appear in the same position as those which formed the reticulum. During the divergence of the chromosomes, the free ends are directed towards the mesial plane, and on the reconstruction of the daughter-nuclei these ends form corresponding lobes of the nucleus. During the following division the chromosomes make their appearance in the same position, their 'ends lying in the nuclear lobes as before.' From this and similar evidence, the chromosomes must be looked upon as elementary organisms, leading an independent existence in the cell.



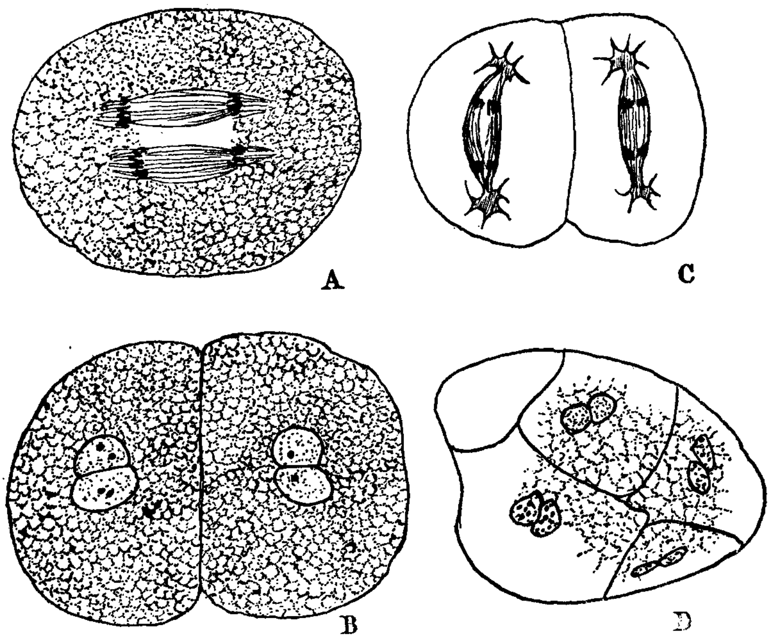
EVIDENCE OF THE INDIVIDUALITY OF THE CHROMOSOMES. ABNORMALITIES IN THE FERTILISATION OF ASCARIS. (Boveri.)

A. The two chromosomes of the egg-nucleus, accidentally separated, have given rise each to a reticular nucleus (♀, ♀); the sperm nucleus below (♂). B. Later stage of the same, a single chromosome in egg nucleus, two in the sperm nucleus. C. An egg in which the second polar body has been retained; $p.b_2$. the two chromosomes arising from it; ♀ the egg chromosomes; ♂ the sperm chromosomes. D. Resulting equatorial plate with six chromosomes.

Boveri, applying this reasoning to the fertilisation of the egg, came to the conclusion that 'we may identify every chromatic element arising from a resting nucleus with a definite element that entered into the formation of that nucleus, from which the remarkable conclusion follows that in all cells derived in the regular course of division from the fertilised egg one half of the chromosomes is of strictly paternal origin, the other half of maternal.'

Boveri's hypothesis was severely criticised at the time, but later observations made by Rückert and others have clearly proved the truth of his theory.

Rückert and Hacker have shown, that in *Cyclops*, the paternal and maternal chromosomes remain separated during the anaphase, and also give rise to double nuclei in the two-cell stage. Herla and Zoja show that if the variety of



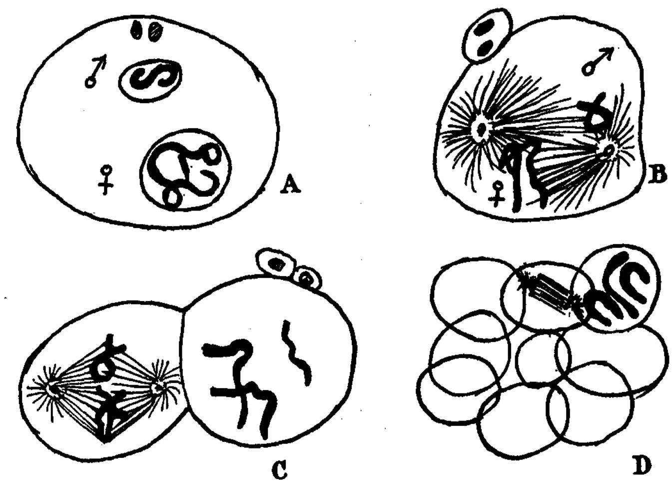
INDEPENDENCE OF PATERNAL AND MATERNAL CHROMATIN IN THE SEGMENTING EGGS OF CYCLOPS.

A. First cleavage figure. complete independence of paternal and maternal chromosomes. B. Resulting two-cell stage with double nuclei. C. Second cleavage; chromosomes still in double groups. D. Blastomeres with double nuclei from the eight-cell stage. (A–C. from Rückert, D from Hacker.)

Ascaris having two chromosomes (*bivalens*) be fertilised with a spermatozoon of the variety *univalens* having one chromosome, the three chromosomes appear at each successive cleavage, and the paternal chromosome, from its smaller size, can be distinguished from the two maternal ones at each division.

PHYSIOLOGICAL RELATIONS OF NUCLEUS AND CYTOPLASM.

Claude Bernard maintained that chemical synthesis, the process by which organic compounds are built up, and morphological synthesis, by which these compounds are arranged into an organised body, are different phases of the same phenomenon, and that both are the result of nuclear activity. A few



HYBRID FERTILISATION OF THE EGG OF ASCARIS MEGALOCEPHALA, VAR. BIVALENS BY THE SPERMATOZOON OF VAR. UNIVALENS.

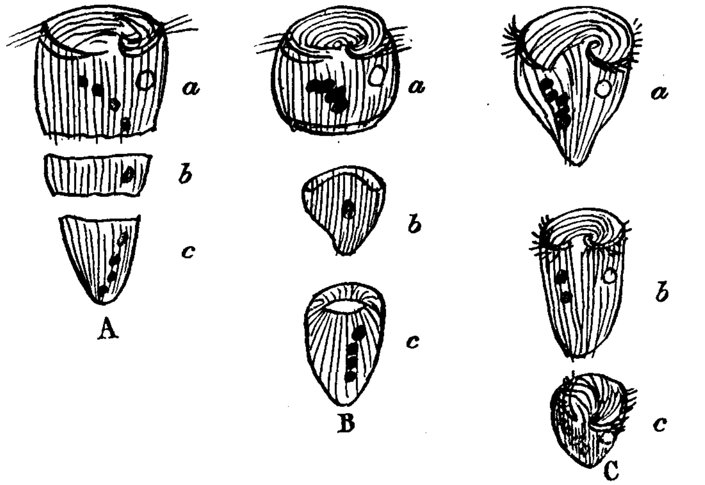
A. The germ-nuclei shortly before union. B. The cleavage figure forming, the sperm nucleus has given rise to one chromosome (♂) the egg nucleus to two (♀). C. Two-cell stage dividing showing the three chromosomes in each cell. D. Twelve-cell stage, with the three distinct chromosomes still shown in the primordial germ-cell. (Herla.)

experiments will suffice to prove that morphological and chemical synthesis are the result of nuclear action, and therefore that the nucleus must be looked upon as the essential organ of inheritance.

Besides experiments on unicellular forms, evidence to the effect that the nucleus is the organ of inheritance will be brought from such phenomena as mitosis, maturation, and fertilisation.

Experiments on Unicellular Forms.—Evidence as regards the behaviour of enucleated and nucleated fragments.

Nussbaum took the infusorian *Oxytricha* and cut it into two portions, one portion containing the nucleus, the other fragment being without any trace of nuclear material. The wound in the nucleated portion quickly healed, the missing portion became regenerated, and a perfect form resulted. The enucleated portion, which consisted only of cytoplasm, showed no signs of vital reaction, and rapidly died. Nussbaum con-



REGENERATION IN STENTOR.

A. Divided into three parts, each containing portion of the nucleus. B. The three portions shortly afterwards. C. After twenty-four hours, each forming a perfect animal. (After Gruber.)

cluded from the above that the faculty of constructive metabolism, or it may be termed the power of regeneration, was inherent in the nucleus.

Gruber repeated these experiments on another infusorian, *Stentor*. A fragment which contained a large portion of the nucleus underwent complete recovery and regeneration in twenty-four hours. A fragment possessing only a small particle of the nuclear material substance recovered very slowly. Any portion in which there was no nuclear material present showed no signs of regeneration, though it might continue to live for some time. It has been further demontrated that if *Stentor* be violently shaken it breaks up into fragments of every possible size, and that a portion as small as 1–27th of the original animal, provided it contained the nucleus underwent complete regeneration. All the portions without nuclear material die.

Verworn has shown that in the foraminifer *Polystomella* nucleated portions possess the power of repairing the shell; portions without nuclear material cannot do this. It has been shown that non-nucleated fragments of *Amœba* may live as long as fourteen days. The movements gradually cease, the function of digestion is arrested, and it is incapable of secreting the slime by which it adheres to the substratum.

Verworn has further shown that both in infusoria and rhizopods non-nucleated portions live for a considerable length of time, perform normal movements, respond to various stimuli, and are also able to take up food material. They have lost, however, the power of digestion and secretion, and therefore must of a necessity die prematurely. In connection with this exceedingly interesting subject students of physiology will at once recall to mind the Wallerian law of degeneration. Waller's law may be included in the statement that 'a nerve degenerates when removed from its trophic centre.' The motor nerves, whose function it is to carry impulses to the muscles of the body, arise from large branched cells situated in the grey surface matter of two adjacent and parallel convolutions of the brain, and passing along a well-defined course enter the spinal cord, down which they travel, leaving it at different levels according to their final destination. It is important to note, however, that before emerging from the cord (it matters not at what level) they communicate with another set of branched nerve-cells situated in the anterior or frontal aspect of the cord, and known as the anterior vesicular column. Having established this communication they proceed to their final termination, viz. the voluntary muscles of the body and limbs.

Should a number of the cells on the cortex cerebri, from which these nerves arise, be damaged, those nerve fibres coming from the affected cells will degenerate downwards as far as the anterior vesicular column. These same nerve-fibres will not degenerate any further, but will retain their physiological integrity. Should, however, the cells of the anterior vesicular column with which these fibres are in connection be damaged, then the motor nerves will degenerate right to their peripheral endings in the muscles.

It is therefore evident that the branched cells of the brain surface referred to exert a powerful influence on the nerve fibres emanating from them, this influence being of such a nature that damage to these cells will be followed not only by loss of function in the nerve tracks, but also degeneration of the constituent fibres. The same statement applies to the branched cells of the anterior vesicular column, which, if damaged, will be followed by loss of function and descending degeneration to the periphery.

From these facts it will at once be concluded that the motor nerves are under the control of two great trophic centres, one located on the surface of the brain (Rolandic area), the other in the spinal cord.

To the first Professor Wyllie has given the name of First Trophic Realm, while the other has been named by the same eminent authority the Second Trophic Realm. The sensory nerves have their own special trophic realm quite distinct from the motor ones. The large multipolar ganglion cells constituting these trophic centres are furnished with well-defined nuclei; and it is in these nuclei that the powers of nourishment, regeneration, and maintenance of the stability of the nerve reside. Every experiment goes to prove that destructive metabolism may go on in the cytoplasm of a cell which has been robbed of its nucleus. The result of this metabolic process is contractility, &c., of the protoplasmic mass. These phenomena, however, after a period of variable length cease, and death ensues. The reason why premature death always supervenes is that the faculty of chemical and morphological synthesis is not present in the cytoplasm, but is a special inherent property of the nuclear material. It is the nucleus which initiates these important phenomena in the cytoplasm, by which it is enabled to digest and store up food material to form a reserve of potential energy for future use. The cytoplasm, being devoid of this synthetical faculty and being merely endowed with the property of destructive metabolism, uses up its stored energy and soon dies. It is therefore of the utmost importance to remember that the nucleus initiates the phenomena of both chemical and morphological synthesis, a fact of essential value in support of the theory of inheritance.

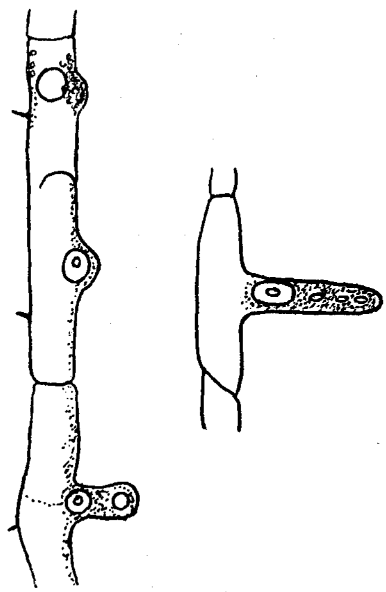
The study of the cells of plants has added weight to the above evidence. It has been shown that detached fragments of certain algæ which were devoid of nuclear material were incapable of developing an envelope of cellulose. The cells of certain forms can be broken up into portions, some of which are nucleated, others non-nucleated : the nucleated fragments clothe themselves in a new garment of cellulose, and by the process of morphological synthesis regenerate into complete plants, down to the minutest detail. The non-nucleated portions, while able to form starch on account of their contained chlorophyll, are unable to use it, neither can they develop a new covering of cellulose, neither can they grow, nor regenerate lost portions.

Position and Movements of the Nucleus

Observers have clearly demonstrated that local growth of a cell-wall is always associated with a previous migration of the nucleus to the point where the growth is taking place. In connection with the cells of the epidermis the nucleus is at first placed centrally ; when growth of the wall occurs the nucleus moves towards, and remains continuous with, the growing surface. That this is not a movement in search of light and air is proved by the fact that in many cells the nucleus moves to the inner and not the outer wall, and there causes thickening and growth.

That the process of growth is initiated by the nucleus is beautifully illustrated in the case of the root-hairs in the pea, in which the first rudiment of an outgrowth always occurs in the vicinity of the nucleus, the nucleus passing outwards in the direction of the growing hair. An exception to this would at first appear in the case of the hairs of aerial plants, in which the nucleus lies near the base of the hair; the discrepancy, however, is only apparent, as it has been definitely shown that in these cases the growth is basal and not apical.

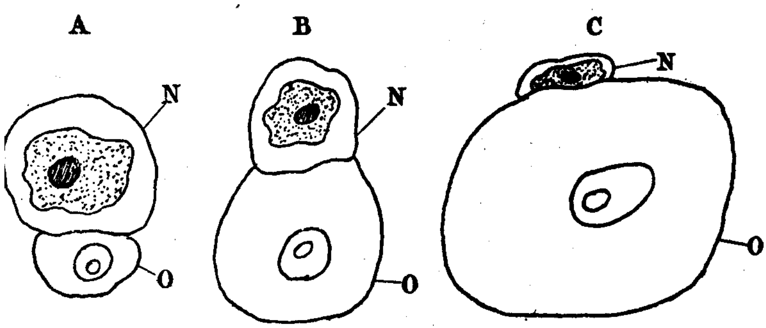
From the above it will at once be conceded that the nucleus initiates morphological synthesis, the result of its presence being the orderly and natural development of the structure.



Position of Nuclei in Growing Root Hairs of the Pea.
(Haberlandt.)

According to Korschelt 'there is a definite correlation, on the one hand, between the position of the nucleus and the source of food-supply, on the other hand between the size of the nucleus and the extent of its surface and the elaboration of material by the cell.' In proof of the latter, we have the enormous nuclei of secreting cells, these nuclei being very branched, so that there is a maximum of their surface brought into action. This kind of nucleus, with its associated function, is well exemplified in the case of the Annelids, in some forms of which the egg is closely attended by a nurse-cell which is attached to its side. In the case of the Annelid *Ophryotrocha* the nurse-cell is at first considerably larger than the egg itself, possessing a large nucleus loaded with chromatin. While the egg-cell grows at a great rate, there is a corresponding rapid diminution in the size of the nurse-cell, which, becoming a mere rudiment, finally disappears. From this it is evident there is a very close association between the nurse-cell and the growing egg.

The observations of Wheeler on another form are of special interest. In this case the egg-cell is accompanied by two



Egg and Nurse-cell in the Annelid, Ophryotrocha. (Korschelt.)

A. Young stage, the nurse-cell at (N) is larger than the egg (O). B. The ovum growing. C. Degeneration of the nurse-cell (N).

nurse-cells, one placed at either end. Quoting from Wheeler, 'these cells fuse bodily with the egg, one having something to do in forming the vacuolated cytoplasm at the animal pole, the other in forming the granular cytoplasm at the vegetable pole.' ('The Maturation, Fecundation, and early Cleavage in *Myzostoma*.') This determination of the polar axis maintains in the ripe ovum.

In the earwig *Forficula* the egg-cells are accompanied by large nutritive nurse-cells, these cells possessing well-defined nuclei richly endowed with chromatin.

From the above examples one is naturally drawn to the conclusion that the nurse-cell greatly assists in, if it is not wholly responsible for, the elaboration of the cytoplasm of the egg, and also that the very marked development of the nucleus in these cells is correlated with this function.

With regard to the position of the nucleus and the source of food supply, one most interesting case only will be mentioned, viz. that of the water-beetle *Dytiscus* in which Korschelt was able to watch the phenomena in the living form. The eggs lie alternating with nutritive cells. These nurse-cells contain granules which are believed to pass into the egg. That such is the case is all but evident from the fact that the egg contains quantities of similar granules, which are seen lying in masses extending from the nurse-cells right to the germinal vesicle, which they often envelop. The germinal vesicle (egg-nucleus) now assumes the function of amœboid movement, and extends its false limbs always towards the mass of granules.

The exceedingly rapid growth of the germinal vesicle at this period points to the conclusion that the granules are absorbed into its substance.

All the observations made go to show that the nucleus of the cell plays an important part in the process of nutrition, and that it obtains a maximum activity during the phases which are characterised by greatly increased growth. It is therefore evident that, so far, the behaviour of the nucleus corroborates and is in harmony with the results obtained from experiments on one-celled forms.

The Nucleus in Mitosis.

W. Roux was the first to point out that 'the essential operation of nuclear division is the division of the mother-granules' (chromatin grains); 'all the other phenomena are for the purpose of transporting the daughter-granules derived from the division of a mother-granule, one to the centre of one of the daughter-cells, the other to the centre of the other.' The cytoplasm, on the other hand, merely undergoes a mass division.

The great central fact must be insisted on that the chromatin of the mother-cell is 'distributed with the most scrupulous equality to the nuclei of the daughter-cells,' and that in this regard there is a most remarkable contrast between nucleus and cytoplasm. This fundamental process of cell-division is characteristic of all living forms, and from this fact alone it is evidently a phenomenon of the most profound importance.

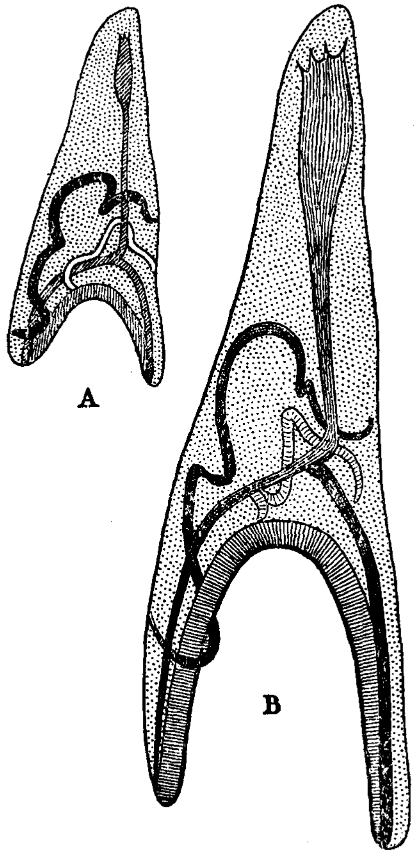
This radical difference between cytoplasmic and nuclear division, by which in the case of the nucleus the chromatin is passed on from the mother-cell to its progeny, leads one irresistibly to the only logical conclusion—that chromatin is the physical basis of heredity.

The Nucleus in Fertilisation.

The facts derived from the process of fertilisation lend a weight to the argument in favour of the nucleus which is overwhelming. As is well known, the ovum supplies practically all the cytoplasm for the embryonic body, the amount derived from the spermatozoon being infinitesimal, and yet the influence of the sperm on the offspring is quite as great as that of the ovum.

The chromatin of the germ-nuclei is divided with absolute equality between the first two, and very probably to all the later-developed cells. That this equal division of the chromatin among all later-formed cells is practically a certainty must be conceded from the experiments of Rückert and others described elsewhere. It is therefore evident that the character of the cell is the result of nuclear action, and that on account of the equal distribution of the maternal and paternal chromatin to every cell descended from the original germ-nuclei we get an insight into the remarkable fact that every part of the offspring may be like either or both parents.

Boveri performed a series of brilliant experiments with the eggs of two different species of sea-urchins, *Echinus microtuberculatus* and *Sphœrechinus granularis*, which are very common in the Bay of Naples. If the minute eggs of either of these species are violently shaken with a little sea-water in a suitable vessel, they break up into various-sized fragments, some of which contain nuclei, others not. Boveri found that these fragments, if fertilised, developed into normal larvæ. The non-nucleated as well as the nucleated portions developed in the usual manner, the spermatozoa entering both with equal agility. The larval forms of *Echinus* and *Sphærechinus* are very different in shape, and after a couple of days' development can be recognised with great ease.



A. Dwarf arising from an Enucleated egg fragment of *Sphærechinus granularis*, fertilised with spermatozoon of *Echinus microtuberculatus*, and showing purely paternal characters. B. Normal *Echinus microtuberculatus*, Boveri. It will be seen they are practically identical except as regards size.

Having made quite sure of these facts, Boveri cross-fertilised the eggs of *Sphærechinus* with the sperm of *Echinus*. The resulting larvæ were of a form midway between that of the parents, showing certain characteristics of each. This hybrid formed a new type which was constant, and was never known to simulate either *Echinus* or *Sphærechinus* to such a degree as to be mistaken for them.

Four important factors are thus established:—

1. The constancy of *Echinus* larval type.
2. The constancy of *Sphærechinus* larval type.
3. The constancy of the hybrid between *Echinus* ♂ and *Sphærechinus* ♀.
4. The ability to secure non-nucleated *Sphærechinus* fragments which were capable of fertilisation.

The final test would be to cross-fertilise non-nucleated portions of *Sphærechinus* with *Echinus* sperm. The kind of larvæ resulting from this cross would decide the question. If the resulting larvæ are of a hybrid type, then both nucleus and cytoplasm determine the hereditary characters. If pure *Sphærechinus* results, then the cytoplasm is the bearer of the hereditary qualities. Should, however, the result be of the pure *Echinus* type, then to the nucleus of the spermatozoon alone can be credited the power of determining the quality of the offspring. The larvæ obtained by Boveri were of pure paternal or *Echinus* type, there being no taint whatever of the maternal element. The development of these larvæ has been brought about solely by the nucleus of the spermatozoon. Thus by pure experimental evidence the chromatin material has been shown to be the physical basis of heredity, the cytoplasm which is represented by *Sphærechinus* having had no influence in determining the type of larva which results.

The Nucleus during the Process of Maturation.

The phenomena occurring during maturation bring out in quite as convincing a manner the great difference between cytoplasm and nucleus. The germ-nuclei undergo the exceedingly complicated series of changes associated with chromatin reduction, thus rendering them absolutely equivalent at the time of their union. When this fact is taken in conjunction with the result of the union of the germ-cells, which produce an embryonic form in which, on the whole, both the characters of the germ-cells have an equal effect, it is to be concluded that the chromatin of the nucleus is the source of hereditary characters, while the position of the cytoplasm is merely that of a subordinate agent.

WEISMANN'S THEORY OF GERMINAL CONTINUITY. *Homo nascitur, non fit.*

The older theories of heredity assumed that the germ-cells were made up of samples taken from every part of the body. This is the conception embodied in Darwin's theory of Pangenesis. These ultra-microscopical particles derived from all the cells of the individual were termed gemmules, and were supposed to circulate in the body, finally coming to rest in the germ-cells. By this theory Darwin sought to explain such phenomena as the regeneration of lost parts, the inheritance of acquired characters (the Lamarckian factors), sexual and non-sexual reproduction, also reversion to a distant ancestor.

The hypothesis (which Darwin himself described as only provisional) was one of the first in which an attempt was made to account for the above phenomena. It, however, never received much support, there being no evidence of the existence of gemmules, and the idea of so many millions of these particles finding a resting-place in the germ-cells was incomprehensible. Darwin's theory, however, did one great service to the science of biology—it stimulated thought, and led to the development of other theories which finally culminated in Weismann's celebrated doctrine of Germinal Continuity.

The central conception of Weismann's theory is that the germ-cells possess an independence of their own, that they are quite distinct from the body or somatic cells; also that the germ-cells of one generation give rise, not only to the bodies of the next generation, but also to their contained germ-cells; in other words, the body cannot produce germ-cells, but merely contains them.

Weismann challenged the whole of the Lamarckian principle in the following words: 'I do not propose to treat of the whole problem of heredity, but only of a certain aspect of it—the transmission of acquired characters, which has been hitherto assumed to occur. In taking this course I may say that it was impossible to avoid going back to the foundation of all phenomena of heredity, and to determine the substance with which they must be connected. In my opinion this can only be the substance of the germ-cells, and this substance transfers its hereditary tendencies from generation to generation, at first unchanged, and always uninfluenced in any corresponding manner by that which happens during the life of the individual which bears it.

'If these views be correct, all our ideas upon the transformation of species require thorough modification, for the whole principle of evolution by means of exercise (use and disuse) as professed by Lamarck, and accepted in some cases by Darwin, entirely collapses.' (See 'Essays on Heredity,' vol. i., by A. Weismann, Clarendon Press, Oxford, 1889.)

Continuing in the same line of thought, he maintains the absolute impossibility of acquired characters being transmitted, and also how inconceivable it is that changes in the body or 'soma' should affect the protoplasm of the germ-cells in such a manner as to produce similar changes in the offspring. He asks—How is it possible that the dexterity in the hand of a piano-player can so affect the structure of the germ-cells as to produce an equivalent dexterity in the hand of the child?

Weismann, in fact, maintains that none of the so-called cases of transmission of acquired characters will stand a scientific test.

The child inherits from the parent germ-cell, not from the parent body, and the germ-cell owes its characteristics not to the body which bears it, but to its descent from a pre-existing germ-cell of the same kind. From the point of inheritance, the body merely carries the germ-cells, which are as it were held in trust for the development of future generations. According to Sir Michael Foster, the animal body is in reality a vehicle for ova; and after the life of the parent has become potentially renewed in the offspring, the body remains as a cast-off envelope whose future is but to die.

The question asked by the older biologists was—How do the characters of the organism get into the germ-cells which it produces? The real question is—How are the characters of an organism represented in the germ-cell which produces it? To understand the relation existing between successive generations, we should say in the words of Samuel Butler, not that a hen produces another hen through the medium of an egg, but that a hen is merely an egg's way of producing another egg.

To put the problem in its simplest form, the question is, not how the characters get into the germ-cells, but how the characters are represented in the germ-cells.

Weismann[1] draws a very sharp line between the body substance, or body plasm, and the germ plasm. To quote an example: An egg contains germ plasm, which was derived from that of the parent; the egg develops and so does the germ plasm, and gradually the germ plasm becomes converted into body plasm, which forms the resulting chick. Some of the germ plasm, however, is not used up to form body substance, but remains as such, forming the germ-cells of the next generation. As a Weismannian axiom allow me to state that, while germ plasm may be and is converted into body plasm, body plasm can never become germ plasm.

In this one statement lies the explanation of what is gradually becoming an accepted fact, viz. that any change affecting the body-cells but not the germ-cells cannot be transmitted to future generations. Thus acquired characters (Lamarckian factors) in the true sense cannot be inherited. The germ plasm of one generation is passed on to the next, and so on and on, and influences coming from without cannot affect the germ-cells, and therefore cannot be transmitted. The germ-cells must be looked upon as the links in a long, unbroken chain of germ plasm, which under certain conditions, usually the union of two germ-cells, produce a body, the germ-cells still continuing their existence in this body. Thus we get the conception of a long line of germ plasm, budding out from which at regular intervals is a new generation, the individual or individuals of

[1] *Mendelism in Theory and Practice*, E. Wynstone-Waters.

which still carry in their bodies a supply of the germ plasm. The generations or buds attached along this continuous chain are mortal; the germ plasm itself, however, only ends when the individual containing it dies without issue. We must therefore look upon the body as a new formation which soon ceases to live, but which passes on to its offspring a portion of the original germ plasm; the germ plasm itself having existed far back through the ages that have been to the very commencement of all life.

As we have already seen, during the maturation of the germ-cells half of the chromosomes or germ plasms will be removed, and the next generation will receive a fresh mixture. It is therefore evident that the chromosomes of any single individual contain germ plasms descended from various ancestors. In fact, the chromosomes must be looked upon as containing a mosaic of ancestral germ plasms. Different individuals will contain different mixtures, and this explains Weismann's hypothesis of the origin of variations. Varying combinations of ancestral plasms will bring about differences in individuals, new combinations will occur in every fertilised ovum, and as a result there must be variations between individuals.

Any influence which acted directly as a stimulus on the germ plasm may so modify it that the effects of this stimulation may be transmitted. The chromosome is a battlefield in which the units of the germ plasm are carrying on a desperate struggle among themselves for nourishment; some will acquire more nourishment than others, and should this line of increase be carried on in the chromosomes of successive generations, certain characters (corresponding to the glutted units) would become accentuated, while others (corresponding to the attenuated ones) would diminish. These variations, arising as they do in the germ plasm, will of necessity be inherited, and will differ in the most radical manner from any changes brought about in the body during life as a result of environment; these latter changes coming from without cannot reach or affect the germ-cells, and therefore cannot be transmitted.

'The distinction between these characters of an organism which it acquires by use or disuse during its life, or which are impressed upon it by its environment, and those characters, which it receives as a birthright from its parents or have originated in the germ from which it has sprung, was not clearly perceived until Weismann's teaching had taken root, but his central position is now the basis of all modern work on heredity and has introduced a different temper into the believers of progress. Whilst it was still possible to hold that characters or attainments acquired during the lifetime and activity of the organism were commonly transmitted to its descendants, a rapid and constant evolution in an upward direction seemed possible for the human race. Man had only to strive, his descendants would proportionally increase in virtue, and a race of men would be evolved which might know or even practise the proscriptions of the Mosaic dispensation from their earliest infancy. The realities of history and heredity do not sanction such dreams, and we must be content to know that while man may lose almost everything by the loss of a tradition, he can never by vicarious effort spare his descendants the pain of assiduously acquiring it by practice.' [1]

I will conclude with a quotation from Prof. Punnett's classical Essay on Mendelism. 'Education is to a man what manure is to a pea. The educated are in themselves the better for it, but their experience will alter not one jot the irrevocable nature of their offspring. Permanent progress is a question of breeding rather than of pedagogics; a matter of gametes, not of training. As our knowledge of heredity clears, and the mists of superstition are dispelled, there grows upon us with ever-increasing and relentless force the conviction that the creature is not made but born.' [2]

[1] *Primitive Animals.* By Geoffrey Smith.
[2] *Mendelism.* By R. C. Punnett.