CHPTER IV.

A NEW THEORY OF HEREDITY.

The objection to the hypothesis of pangenesis would be almost entirely removed if it could be simplified—Statement of a new theory—Heredity is due to the properties of the egg—Each new character has been impressed upon the egg by the transmission of gemmules—Tendency to form gemmules is due to the direct action of external conditions—The ovum is the conservative element—The male cell is the progressive element—This theory has features of resemblance to most of the hypotheses which have been noticed—It fills most of Mivart's conditions also—It is not necessary to assume that the ovum is as complicated as the adult—There are many race characters which are not congenital—There are many congenital characters which are not hereditary—Direct action of external conditions—Our theory stands midway between Darwin's theory of natural selection and Lamarckianism.

If the hypothesis of pangenesis could be so remodelled as to demand the transmission of only a few gemmules from the various parts of the body to the reproductive elements, instead of the countless numbers which are demanded by the hypothesis in its original form, we should escape many of the objections which have been urged against it.

If it can be shown that these few gemmules are not necessarily present at all times and in all parts of the body, but only occasionally and in certain regions, we shall escape the difficulty presented by Galton's experiments, and the presumption in favor of the hypothesis will be greatly increased.

If the theory of heredity, in its new form, agrees with all that we know of the functions of the two sexual elements and if, besides furnishing an explanation of all the phenomena which are accounted for by other hypotheses, it embraces new classes of facts as well, the presumption in its favor becomes still greater.

Finally, if it leads to the discovery of new and unexpected relations between phenomena, and to the establishment of laws which group and interpret phenomena between which no connection had previously been recognized, its value must be acknowledged.

I venture, then, to advance a new theory of heredity, which, briefly stated, is as follows:

The union of two sexual elements gives variability. Conjugation is the primitive form of sexual reproduction. Here the functions of the two elements are alike, and the union of parts derived from the bodies of two parents simply insures variability in the offspring.

In all multicellular organisms the ovum and the male cell have gradually become specialized in different directions.

The ovum is a cell which has gradually acquired a complicated organization, and which contains material particles of some kind to correspond to each of the hereditary characteristics of the species.

The ovum, like other cells, is able to reproduce its like, and it not only gives rise during its development to the divergent cells of the organism, but also to cells like itself.

The ovarian ova of the offspring are these latter cells, or their direct unmodified descendants.

Each cell of the body is, in a morphological sense, an independent individual. It has the power to grow, to give rise by division to similar cells, and to throw off minute germs. During the evolution of the species it has by natural selection acquired distinctive properties or functions, which are adapted to the conditions under which it is placed. So long as these conditions remain unchanged it performs its proper function as a part of the body; but when, through a change in its environment, its function is disturbed and its conditions of life become unfavorable, it throws off small particles which are the germs or "gemmules" of this particular cell.

These germs may be carried to all parts of the body. They may penetrate to an ovarian ovum or to a bud, but the male cell has gradually acquired, as its especial and distinctive function, a peculiar power to gather and store up germs.

When the ovum is fertilized each germ or "gemmule" unites with, conjugates with, or impregnates, that particle of the ovum which is destined to give rise in the offspring to the cell which corresponds to the one which produced the germ or gemmule; or else it unites with a closely related particle, destined to give rise to a closely related cell.

When this cell becomes developed in the body of the offspring it will be a hybrid, and it will therefore tend to vary.

As the ovarian ova of the offspring share by direct inheritance all the properties of the fertilized ovum, the organisms to which they ultimately give rise will tend to vary in the same way.

A cell which has thus varied will continue to throw off gemmules, and thus to transmit variability to the corresponding part in the bodies of successive generations of descendants until a favorable variation is seized upon by natural selection.

As the ovum which produced the organism thus selected will transmit the same variation to its ovarian ova by direct inheritance, the characteristic will be established as an hereditary race characteristic, and will be perpetuated and transmitted, by the selected individuals and their descendants, without gemmules.

According to this view, the origin of a new variation is neither purely fortuitous nor due to the direct and definite modifying influence of changed conditions. A change in the environment of a cell causes it to throw off gemmules, and thus to transmit to descendants a tendency to vary in the part which is affected by the change.

The occurrence of a variation is due to the direct action of external conditions, but its precise character is not. My view of the cause of variation is thus seen to be midway between that accepted by Darwin and that advocated by Semper and other Lamarkians.

Many naturalists have given reasons for believing that the transmutation of species is not always gradual, but that a form which has long persisted without change may suddenly vary greatly, and thus give rise to a strongly-marked race of descendants. Mivart has discussed this subject at considerable length, and he quotes Professor Huxley's opinion that "we greatly suspect that Nature does make considerable jumps in the way of variation now and then, and that these saltations give rise to some of the gaps which appear to exist in the series of known forms;" and Dall has proposed the term *saltatory evolution* for abrupt change of this kind. According to the theory here advanced, variation must tend to accumulate or culminate, and one variation must cause others; for when any particular cell changes, the harmonious adjustment between it and adjacent or related cells will be disturbed, and all the cells which are thus affected will tend to throw off gemmules, and thus to induce variability in the same cells of succeeding generations. Then, too, a gemmule may unite or conjugate in the ovum with particles which are not perfectly equivalent to it, but only very closely related to it. Thus a variation may affect a considerable number of related cells at the same time, or a variation in any part may cause in succeeding generations the variation of homologous parts, thus producing what Darwin has called *correlated variation.* We can also understand how it is that when any part of a complicated organ varies, variations in other parts of it are also soon presented for the action of natural selection, so that an harmonious readjustment is soon established.

According to this view we must believe that all the characteristics which are established as true race-characteristics, as hereditary peculiarities of the species, are transmitted by the ovum, which has in itself the power to develop, when excited by a proper stimulus which may or may not be due to impregnation, into a new individual of the parent form.

New variations, on the other hand, are produced through the agency of gemmules thrown off from cells like those in which the variation appears.

Gemmules may penetrate to all parts of the body, and they may thus give rise to bud-variation and to analogous changes; or they may penetrate to an ovarian ovum and give rise to variation without fertilization: but as these phenomena depend upon chance, they are comparatively rare, while the aggregation of the gemmules in the male cell and their transmission by impregnation are normal processes.

According to this view, the male element is the originating and the female the perpetuating factor; the ovum is conservative; the male cell progressive. Heredity or adherence to type is brought about by the ovum;

variation and adaptation through the male element; and the ovum is the essential, the male cell the secondary, factor in heredity.

The various hypotheses which we have noticed have little in common, and it is therefore interesting to note that they all present points of resemblance to the one which is here advanced, and that this alone has features in common with them all.

Like Aristotle and the ancients, we must believe that the two reproductive elements play widely different parts. Like Bonnet and Haller, we see that the structure of the adult is latent in the egg.

The mode of origin and transmission of the gemmules is essentially like Darwin's conception, and we must acknowledge that Buffon's view of the part played by his organic molecules was very near the truth.

The analogy upon which Haeckel lays so much stress is readily explicable by our theory, for since each stage in the evolution of the species has been impressed by gemmules upon the egg, it is, in truth, *only natural* that the developing organism should mirror the ancestral history of its species; and, finally, our view of the origin of the properties of the ovarian egg is identical with that given by Jäger in his explanation of reversion.

An honest attempt to reason from the phenomena of nature can hardly fail to result in the discovery of some little truth, and I think we may hope that all these points of agreement with hypotheses which are manifestly inadequate can only be due to the presence in them all of some portion of the true light of nature.

Mivart, who believes with Darwin that natural selection has been a *great* but *not the exclusive* means through which organisms have been modified, has attempted in Chapter xi. of his book on the *Genesis of Species* to indicate some of the requisites of a true theory of the origin of species. This valuable and instructive book is well worthy of careful study, and most students will find in it much material for reflection. Mivart has no explanation of his own to offer, and some of the characteristics of the explanation which he believes in, but does not furnish, are conspicuously absent in the present attempt as well as in Darwin's work; but it is interesting to note that many of the conditions which he enumerates are complied with by our theory of heredity, and by no other explanation which has ever been proposed. Thus he says (p. 244) that "It is quite conceivable that the material organic world may be so constituted that the simultaneous action upon it of all known forces, mechanical, physical, chemical, magnetic, terrestrial and cosmical, together with other as yet unknown forces which probably exist, may result in changes which are harmonious and symmetrical, just as the internal nature of vibrating plates causes particles of sand scattered over them to assume definite and symmetrical figures when *made to oscillate in different ways by the bow of* a violin being drawn along their edges. The results of these combined internal powers and external influences might be represented under the symbol of complex series of vibrations (analogous to those of sound and light) forming a most complex harmony or a display of most varied colors.

"In such a way the reperation of local injuries might be symbolized as a filling up and completion of an interrupted rhythm. Thus also monstrous aberrations from typical structure might correspond to a discord, and sterility from crossing be compared with the darkness resulting from the interference of waves of light.

"Such *symbolism will harmonize with the peculiar* reproduction, before mentioned, of heads in the body of certain annelids, with the facts of serial homology, as well as those of bilateral and vertical symmetry. Also as the atoms of a resonant body may be made to give out sound by the juxtaposition of a vibrating tuning-fork, *so it is conceivable that the physiological units of a living organism may be so influenced by surrounding conditions (organic and other) that the accumulation of these conditions may upset the previous rhythm of such units, producing modifications in them—a fresh chord in the harmony of Nature—a new species.* . . . It seems probable, therefore, that new species may arise from some constitutional affection of parental forms—an affection mainly if not exclusively of their generative system."

According to the view which I have presented a new variation is caused in essentially the manner which Mivart suggests as probable. The accumulated influence of surrounding conditions, organic and inorganic, does upset the previous rhythm of the physiological units of the living organism, and causes them to give rise to gemmules, and the tendency of the corresponding units of the offspring to vary, is directly due to this constitutional affection of the parental forms.

I have spoken of the egg as containing material particles of some kind to represent each of the hereditary congenital peculiarities of the race. According to this view the egg of one of the higher animals must be a wonderfully complex structure. At first sight it would seem as if it must be as complicated as the adult animal, but a little thought will show that this is by no means the case.

In the first place, there are many structures which enter into the formation of the body without being part of its actual living substance. Nearly every living body consists in part of structures which are in no sense alive, but which are built up by the formative activity of the living protoplasm. The shell of a snail or of an oyster is purely inorganic, and although it is built up by the animal, and is necessary to its existence, it is no more a part of the living substance of the animal than the shell which is picked up and inhabited by a hermit crab. It is true that the oyster's shell is formed by the animal, as part of itself, but the shell does not grow, like living tissues, by the absorption and transformation of nutriment, but by the crystallization of the amorphous mineral matter which is poured out by the living cells of the mantle; and microscopic examination shows that it is not an organized tissue made up of cells, but an aggregate of purely mineral crystals.

Since this is the case it is clear that it is not the shell itself, but a tendency to build the shell, which is hereditary, and is contained in the egg; and an illustration will serve to show that the inheritance of the tendency involves much less complexity in the structure of the egg than the inheritance of the thing itself would imply.

A bee inherits a tendency to build up a comb of wax, and to fill the cells of this comb with honey.

The comb and the honey are due to the vital activity of the bee, just as the shell is the result of the vital activity of the oyster; but the statement that the bee's egg contains something which corresponds to the structural organization to which the tendency is due, is certrinly *not equivalent to a statement that the actual* comb, filled with honey, is represented in the egg. This is just as true of structures which are built up, inside the body, by its vital activity, as it is of those which are built up in the same way outside the body.

When we take into account all structures of this kind which are not parts of the living substance of the organism, but which simply owe their existence to the properties of its living substance, we can readily understand that the complexity of an adult animal may be vastly greater than the complexity of the egg.

In the second place we must recollect that there are many race characteristics which are of constant occurrence without being hereditary.

Organisms are often greatly modified by the direct action of external conditions; for instance, a tree may be dwarfed by insufficient food, or the muscles of a limb may be greatly enlarged by unusual work. If all the individuals of a species are similarly exposed to conditions of this sort, they will all be acted upon in the same way, and the modification which is thus produced will be characteristic of the species, without being hereditary.

To take one of the simplest cases: Trees which grow upon mountain-tops, where they are exposed to extreme changes of climate, and to constant and violent winds, have a very characteristic appearance, which is familiar to all mountain climbers. In some cases this peculiar form is hereditary, and persists in seedlings which are grown in more favored regions, but in other species the transplanted trees show, by losing their peculiarities, that these are due to direct modification.

If a certain species occurs naturally nowhere except in such situations, this species will be characterized by its dwarfed size and by its twisted and distorted branches; but if individuals reared under favorable influences grow and flourish and become regular and symmetrical, we may conclude that the characteristics of each wild individual are caused by its scanty food and constant exposure, and that they are not represented in the egg, and are not congenital.

If this experiment is impossible, if all the transplanted trees die, and if the seeds fail to germinate in fertile ground, there will be no way to show whether the peculiar characteristics of the species are or are not hereditary.

We know that organisms may be modified in many ways by the direct action of external conditions, but a few illustrations will not be out of place.

Hemp-seed causes bullfinches and certain other birds to become black, and we know from the observations of many naturalists that caterpillars which are fed on different kinds of food either themselves acquire a different color, or they may produce moths which differ in color. Many curious cases of this kind have been noticed in birds and insects, and if unnatural food causes deviations from the natural color of a species, it is quite possible that the normal color may in many cases be due directly to the action of the normal or natural food.

Darwin gives many instances of plants which are characterized by a certain peculiarity in one country, while in another country this peculiarity is almost or entirely lacking. Thus when the American sassafras tree is grown in Europe, it loses its aromatic flavor. In India the fibres of flax and hemp are brittle and useless, and the latter plant yields a resinous narcotic substance, hasheesh, which is used as an intoxicating drug, but in England this property is lost and the fibre becomes long and tough. Large, finely-flavored, and brightly-colored American apples, when reared in England, produce fruit of a dull color and poor quality.

In these cases we are unable to state what the determining conditions are, but the fact that peculiarities are made to disappear by a change from one country to another shows that they are not congenital but are due to something outside the plant, which is present in one country but absent in another. The following instance, which is given by Darwin, is most interesting "Mr. Salter, who is well known for his success in cultivating variegated plants, informs me that rows of strawberries were planted in his garden in 1859, in the usual way; and at various distances in one row several plants simultaneously became variegated, and what made the case more extraordinary, all were variegated in precisely the same manner. These plants were removed, but during the three succeeding years other plants in the same row became variegated, and in no instance were the plants in any adjoining row affected." He also says that in certain parts of India the turkey becomes reduced in size with the pendulous appendages over the head enormously developed.

In these cases it is difficult to determine what has caused the change, but in other instances this is more obvious. Thus Darwin states that good authorities assert that horses kept during several years in the deep coal mines of Belgium become covered with velvety hair almost like that of the mole, and he quotes from Dr. Falconer the statement that the Thibet mastiff and goat when brought down from the Himalayas to Kashmir lose their fine wool.

These are only a few of the cases which Darwin gives, and many more might be added from other authorities, but I have given enough to show that external conditions of life may act in one country to cause certain modifications which are entirely absent in another country.

The change of Artemia into Branchippus, by rearing it in fresh water, is one of the most remarkable instances of definite modification due to a change of external conditions. Artemia salina is a small crustacean, found in the salt lakes of America, Europe, and Africa. When this species is kept in water in which the quantity of salt is gradually diminished, it becomes transformed, in a few generations, into what has been described as a distinct species—Artemia Milhausenii—and if the process of diluting with fresh water is continued until it finally becomes perfectly fresh, the Artemia becomes changed into the well-known fresh-water form Branchippus, which has always been considered a distinct genus.

Semper has shown (*Animal Life*, p. 161) that certain definite changes in the size of the fresh-water snail Lymnæa are produced in a short time by confining it in a small quantity of water.

These are a few of the cases where we are able to show, by experiment, that certain race-characteristics are not congenital, but are due to external influences, and we have every reason to believe that the same thing is true in many cases which have never been made the subject of experiment, and in many more where experiment is impossible, since the change would cause death rather than modification.

The possibility that structures of the greatest constancy and importance may not really be hereditary is well illustrated by Hunter's well-known experiments on the sea-gull. In pigeons, and in most birds which feed upon grain, the muscular wall of a portion of the stomach is greatly developed, to form the crushing and grinding gizzard, which is lined with a covering of tough membrane, while the stomach of the gull and of most flesh-feeding birds is soft, and the muscular layer little developed. Hunter fed a sea-gull for a year on grain, and he thus succeeded in hardening the inner coat of the bird's stomach, thus forming a true gizzard; and Darwin quotes from Dr. Edmonston the statement that a similar change occurs twice a year in the stomach of another sea-gull in the Shetland Islands, where this bird frequents the corn-fields and feeds on seeds in the spring, but catches fish during the rest of the year. This observer has noticed a great change in the stomach of a wren which had long been fed on vegetable food; and Menetries states that when an owl was similarly treated the form of the stomach was changed, and the inner coat became leathery, while the liver increased in size. Semper states that Dr. Holmgrin has been able to transform the gizzard of a pigeon into a carnivorous stomach by feeding the bird on meat for a long time.

There is no reason for believing that the few cases known to us are all which are due to the direct action of external conditions, and we must acknowledge that there may possibly be many structural characteristics of animals and plants which are not hereditary, but are constant simply because the conditions which cause them are constant, and as we are only compelled to attribute to the ovum representatives of all the hereditary race characteristics, it will be seen that the structural complexity of the egg may be vastly less than that of the developed organism.

This is not all, however. There may be many congenital race characteristics which are not hereditary.

The various parts of a developing organism are exposed in countless ways to the influence of other parts. The simplest illustration of this fact is the mechanical pressure exerted upon each other by the developing viscera.

This is a subject which is almost outside the province of experiment, for we cannot shut out the influence of any particular organ without removing the organ itself, and the removal of any organ of considerable size is more likely to cause death than to cause modification. The features of microcophalous idiots show us, however, that the shape of the skull and of the face is only due, in part, to heredity, and is, in part at least, due to the size and shape of the brain. In lop-eared rabbits the whole conformation of the skull is altered by the mechanical pressure of the drooping ears, and it is stated that certain monstrosities in the shape of snail-shells are due to the arrested development of the reproductive organs. Moquin-Tanden remarks that with plants the axis cannot become monstrous without in some way affecting the organs subsequently produced from it.

We can see, from the study of domesticated pigeons, that an increase or a decrease in certain organs is a direct cause of modification in other parts. Pouter pigeons have been selected for length of body, and the establishment of a long-bodied race has increased the number of their vertebræ and the breadth of their ribs. Tumblers have been selected for their small size, and the number of ribs and of primary wing-feathers has thus been reduced. Fantails have been selected for their large widely-expanded tails, with numerous tail-feathers, and the size and number of the caudal vertebræ have thus been increased, and the selection of long-beaked carriers has increased the length of their tongues. Cline states that the skull of a ram with horns weighs four times as much as that of a hornless ram of the same age, and Youatt states that in hornless cattle the frontal bones are materially diminished in breadth towards the poll, and the cavities between the bony plates are not so deep, nor do they extend beyond the frontals.

The kidneys of different birds differ much in size, and St. Ange believes that this is determined by the size of the pelvis.

It is plain that if the character of important parts can be thus changed by changes in other parts, the typical or characteristic form of these parts may be due only partially to heredity.

We see then that the structural complexity of an adult animal is due in part to the formation of structures which are not alive, in part to the direct modifying influence of external conditions of life, and in part to the action of one organ of the body upon another, so that the number of features which are directly inherited is very much less than the number which are constant in and characteristic of the species.

It is impossible for us to state at present how many features must be subtracted from the race characteristics of an animal in order to give us the total number of hereditary congenital characteristics. The observations and experiments which are recorded are few in number, but they are sufficient to show us that, in all the higher animals, very considerable deduction must be made; and we may be sure that the mature animal is vastly more complex than the egg. There is still another limiting circumstance which has not yet been mentioned.

Many of the parts of an organism are due to indefinite multiplication of a single element. The simplest illustrations of this fact are the blood corpuscles of vertebrates and the leaves of plants. It is clearly unnecessary to suppose that each vertetrate ovum contains separate particles for all the blood corpuscles, or that each seed contains separate particles for all the leaves which the plant is to produce. All that is necessary is to assume that it contains particles which are capable of producing a single one of these structures, with a capacity for indefinite multiplication, and that surrounding conditions determine how far, and in what places, this power of multiplication shall manifest itself. Most of the organs of the body contain great numbers of cells which are alike both in structure and function, and as it is usually quite impossible to say how far the size of an organ is truly hereditary, and how far it is determined by surrounding conditions, it is, of course, impossible to say to what extent its mature structure is represented in the ovum, but as we know that the size of most organs varies, and may be increased or diminished by external influences, we may be quite certain that the number of *independent cells which make up the tissues and organs* of a mature organism, is very much greater than the number represented by distinct particles in the ovum.

It is not even necessary to suppose that all classes of cells which are present in the adult are represented in the ovum. In a mammal, for instance, certain epithelial cells become converted into hairs, while others become converted into glands or other specialized epithelial structures.

It is not necessary to assume that all of these specializations are represented in the ovum, for we know that ordinary epithelial cells, in a part of the body where no hair is normally developed, may, when inflamed, give rise to hairs. It is therefore quite possible that each epithelial cell may, when excited by the proper influence, tend to become converted into a hair cell. Each cell of the body may possess the tendency to manifest certain properties under certain conditions, and to manifest certain other properties under other conditions, and the descendants of a single cell may thus become modified in several divergent directions, and each modification may be perfectly constant and characteristic of the race without being hereditary; that is, without being represented in the ovum by a particle with the same specialization.

It may seem to some that the assumption that the egg contains particles capable of producing an unspecialized epithelial cell which shall have the power to give rise to all the specialized sorts of epithelial cells, involves just as much complexity of structure as the assumption that each kind of cell is represented in the ovum, but I think an illustration will show that this is not the case.

Training of a certain kind will develop a boy into a good pedestrian, while another sort of training will make him a good shoemaker; but it is surely simpler to assume that he is born with a power to develop the characteristics of a shoemaker under the influence of certain conditions, and those of a pedestrian under other conditions, than to assume that he is born with all the peculiarities of both latent in his organization.

The direct modifying influence of surrounding conditions is a subject upon which very much remains to be done, but we know enough about it already to state that many of the constant characteristics of organisms are due to exposure to constant and uniform conditions rather than to heredity. To what extent this is true we are quite unable to determine, but we can be sure that the organization of the ovum is simpler, and in all probability vastly simpler, than that of the developed organism.

After all these deductions are made the number of strictly hereditary features is very great indeed, and the egg of one of the higher animals must be a marvellous structure, for we know that, after all, most of the characteristics of an organism are not due to the influence of its conditions of life, but to the past history of the race; and Darwin has shown us that the successive changes which have resulted in the evolution of any organism do not, usually, owe their existence to the direct modifying effect of external influences, but to the natural selection of congenital variations.

The fact that our theory requires us to believe that the egg of one of the higher animals is complex beyond our powers of conception, must not be regarded as an argument against the theory, for we are compelled to believe this in any case. The difference between our theory and other attempts to explain the phenomena of heredity, is that it does what no other hypothesis attempts. It furnishes a simple explanation of the manner in which the ovum has acquired its present complexity.

In the following chapters I shall give some of the reasons for believing that the difference between the functions of the sexual elements which the theory requires does actually exist, but even in the absence of this proof it would be natural to conclude that if race modification could be furthered and aided by the divergent specialization of the functions of the two reproductive elements, natural selection would, in all probability, have acted so as to bring such a specialization about.

We know that the influence of natural selection is constantly exerted to seize upon and perpetuate any tendency to division of labor among the organs and tissues and cells of the body, and it is only natural that the successive stages in the specialization of the sexual elements should have been perpetuated like any other useful specialization.