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THE FIRST PRINCIPLES OF
HEREDITY

HEREDITY AND SELECTION
IN SOCIOLOGY

BY

G. CHATTERTON HILL

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THE FIRST PRINCIPLES
OF HEREDITY

WITH 75 ILLUSTRATIONS AND DIAGRAMS

BY

S. HERBERT

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PREFACE

WHILST giving a course of lectures on Heredity to a class of working men and others, I was asked to recommend a textbook which could be read up by the students in order that they might be able to make the best possible use of what they heard during the lectures. I felt extremely sorry that I was unable to comply with that request. I could not find a single book in the English language suitable for that purpose, seeing that, apart from a little superficially written book of no consequence, only the large special textbooks on the subject are available.

As there must be a good many such intelligent and aspiring young people eager for a deeper knowledge of the problem of life, without being at the same time advanced enough to master the larger manuals, I at last decided to follow the advice of my friends and write the book myself.

It will therefore be seen that I claim no originality for the contents of this book. Its purpose is to supply in a simple and yet scientific manner all that may be desirable for the average intelligence to know about Heredity and related questions, without at the same time assuming any previous knowledge of the subject on the reader's part.

S. H.

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THE FIRST PRINCIPLES OF HEREDITY

CHAPTER I

INTRODUCTION

THERE is, perhaps, nothing more striking in the history of mankind than the contrast between life and knowledge. While we have at the source of all life the perpetual renewal of progeny, the great mystery of creation, the one act which goes to make life, as life, possible, we find this is the last problem man has set himself to study and to solve. Nay, whilst science is just waking up to the tremendous task of penetrating into life's mystery of mysteries, civilization has debased the very act of Nature's nursery by making it a shame to mention either deeds or sentiments connected with the facts of reproduction. Heredity and subjects of kindred import are tabooed by polite society ; each man's conscience is called upon to absolve him as well as may be of the task imposed upon him by Nature. He must not ask questions ; instruction is denied him.

It is time this toying with man's holiest of duties ceased. It is time man knew the extent of his obligations and the consequences of his deeds.

Science is at last waking up. Where there was ignorance, a complete gap, half a century ago, knowledge is stepping in—slowly, it is true, tentative and hesitating, but none the less sure. Little enough is known about the laws of heredity, reproduction, sex, and other questions of equal importance, but the little that is known is the privileged

possession of a few trained specialists. The public at large takes no notice of it, or, if at all, talks humorously of it, as of yore, without recognizing man's great responsibility to the future.

In our own days, when the social question has come so prominently to the front, and every consideration is given to the reconstruction of the material basis of society, far too little attention is given to the integral unit of society, the individual, and his connection with society. Evolution has taught us to regard society as a whole, to look on the ever-changing procession of generations as a long interconnected chain, where each link is shaped and influenced by its predecessor, determining in its own turn the nature of the next link. What is the extent of this influence ? What are the forces at work ? What the consequences ? These questions are not mere idle speculations of a curious mind engaged in professional specialism. The consideration of the constitution of each individual enters into the calculation of his social fitness, concerns the welfare of each and all, and has therefore to be considered a right and proper subject for earnest attention, and not to be overlooked or contemptuously brushed aside.

A new era has dawned upon the civilized world. The idea of evolution has changed the whole aspect of the human horizon. We are no longer satisfied with the old homely truths, mere guesses at the destination of man ; but, having lifted somewhat the veil of Nature's purpose, having learnt a little of man's beginning and his development, we have set ourselves seriously to the task of working out our destiny, consciously, and not blindly, as hitherto.

Social Science, rightly understood, is based on two factors : Heredity and Evolution. To understand the world's progress from the new standpoint, and to get a complete grasp of the facts and theories involved ; to be able to form a judgment and add one's little share to the future of mankind ; it is absolutely necessary to make oneself acquainted with the problems of modern Biology, as

expressed in the theories of Heredity and Evolution. It is not sufficient simply to give one's assent to Darwin's theory of the Descent of Man, as so many do, without understanding it ; it is not enough to speak vaguely about Degenera·tion and Race Suicide, without being able at least to grasp the initial facts of the question. It is time that people destined to become citizens learned to know the elementary facts of natural science as revealed in the last fifty years.

Fatherhood and motherhood are a mockery without the serious consideration of their purpose. And how can there be true responsibility without knowledge ?

We talk about the education of the masses. But what has that education meant up to now ? A preparation for life ? It is said so, because all that makes for the purpose of earning one's livelihood is falsely called by that name. Is the making of money, the mere supply of the material wants of the body, the aim and end of our life ? Certainly not ; and yet no preparation is made, no thought is taken for the most serious business of life, the begetting and upbringing of the future generation. It is not as if we were still in the darkness of utter ignorance. Nature herself, through her unending throes of procreation, ever scaling towards a higher and grander humanity, has vouchsafed us a glimpse of her method.

Let us follow her, study her, imitate, and so finally conquer her.

CHAPTER II

I.—INTRODUCTORY.

It has ever been the natural tendency of man to make himself the measure of the universe. Being nearest and best known to itself, the primitive mind essays the first explanation of the forces of Nature in terms of its own consciousness, interpreting the lower order by the higher. This has been the unavoidable course of the history of human knowledge. It is only in the last fifty years that Darwinism has changed all this. Having irrefutably demonstrated the gradual evolution of all beings from the lowest and simplest to the highest and most complex ; having shown the real genetic relationship of the different classes of animals and plants, this new theory has given us at one stroke a real and penetrating insight into many problems of life which up to then had seemed an ever-insoluble enigma.

Instead of vainly trying to explain the lower stages of life in terms of the higher, it has now become the acknowledged method of biological science to interpret the higher by the lower, seeing that the higher organisms have their beginning in the lower, and gradually evolve from them.

It fared not otherwise with Reproduction. To the first investigators reproduction was, as it is now to the man in the street, indissolubly bound up with the idea of sexual mating as it takes place among the higher animals. What happens to be merely an incident in the life of the higher animals and plants, the co-mingling of the two sexes for the propagation of the new generation, is looked upon as

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the very essence of the process. Not unnaturally so, because reproduction was at first only known in man and the higher animals. But since the life cycle of the lower, more primitive organisms has become known, and especially since the advent of the science of comparative anatomy, we have learnt to view the process of reproduction from a different standpoint altogether.

To understand the problem thoroughly we have to begin our study with the lowest organisms, in order to see the process in its simplest form, and then follow it up gradually in its evolution from stage to stage, until it attains its highest form in the mammals, and ultimately in man.

For this purpose, it is necessary, first of all, to give a short résumé of the modern conception of the living organism—that is, of body and cell.

(a) BODY AND CELL.

All living organisms, plant and animal, are composed of cells. The cell which forms the unit of the living being may be defined as the smallest particle of organic matter capable of life. The body consists of a mass of such units —cells various in shape and function, and arranged in a definite manner. One could perhaps get an approximate idea of it by comparing it to a building constructed of bricks and stones of different sizes, colours, and materials.

The contents of the living cell—the protoplasm, as it is called—is semifluid in consistence, and generally enclosed in a limiting membrane, which forms the outer hardened layer of the cell. Within the protoplasm can be distinguished a small round body, the nucleus of the cell, which has a special structure, and is the most important part of the cell, inasmuch as it directs and regulates all the vital processes going on in the cell-body. These functions are assimilation, growth, and reproduction. The cell draws its nourishment from the surrounding medium, and works it up for its own purpose, turns it into protoplasm—*i.e.*,

assimilates it. In this way the cell adds to its substance ; that is, it grows. When it has attained a certain size, which varies for different cells (the average size of a cell is always microscopical, about $\frac{1}{12}$ to $\frac{1}{250}$ inch or less), the cell divides into two daughter-cells, each with its own nucleus and cell-body—a process which will be described later on. We have thus, as the outcome of the growth of the cell, reproduction in its simplest form.

The lowest organisms, as Amœbas and Infusorians among animals, or Bacteria and Yeast among plants, consist only of a single cell. They are called Protista—viz., Protozoa, if they belong to the animal kingdom, and Protophyta if belonging to the plants. In the next stage we find an aggregation of cells, all more or less alike in structure, forming cell-colonies, as the Algæ (plants) or Volvocineæ (animals). Gradually differentiation arises among the cells ; an inner and outer layer is formed, each assuming different structure and function.

FIG. 1.—A CELL.

(From H. W. Conn, " The Story of Life's Mechanism.")

cw, the cell wall ; *pr*, the cell substance or protoplasm ; *n*, the nucleus.

As we ascend higher through the classes of animal and plant species further differences ensue ; tissues and organs are formed for specific purposes with specialized anatomical structure, until we reach the highest stage in the mammals, and finally in man. All organisms composed of many cells are called Metazoa and Metaphyta, in distinction from Protozoa and Protophyta respectively. However great the difference between the lowest and highest organisms may be, there is this one fundamental agreement : they all are made up of cells, variously arranged and variously adapted in structure and function for their specific purpose.

As we can follow step by step the gradual evolution of the higher types of organisms from the lower by the agglomeration and gradual differentiation of cells, so we can trace a parallel development in each single individual. Every animal or plant starts life as a single cell. This mother-cell divides and redivides, forming a mass of cells, which gradually differentiate into layers, tissues, and organs, finally to build up the complete body in all its complexity. The construction of the body, then, from the first mother-cell to its final size and form, is thus due to a continuous reproduction of cells. The growth of each part of the body is kept up by the multiplication and addition of cells arising from the old cells already present. In fact, growth, as we see, is nothing but a process of reproduction of cells. As long as the organism grows, the material for the additional growth is supplied by the old cells, which divide to form the new ones.

But, at the same time, with this process of growth and building up of the body another process is going on in the organism—a gradual wearing down and simultaneous renewal of the worn-out parts of the body. Cells grow old, die, and are replaced by new ones. This process is a very familiar one. Everybody knows that skin, hair, and nails are periodically renewed under normal conditions. The small scales of the skin which are regularly thrown off are nothing else than old dried-up cells, which, if in excess, form on the head the well-known dandruff. Hair, which is nothing but a cylinder of cells, falls out regularly, and is replaced. The moulting of birds, snakes, crabs, etc., is a well-known phenomenon. There is every reason for assuming that the other cells in the different organs of the body are also periodically renewed, as we know that the mucous linings of mouth, intestine, etc., shed their cells regularly.

We recognize, then, a constant process of regeneration of the body-cells as a normal physiological function. If the gradual decay of cells is not sufficiently made up by

new ones, if, as it is scientifically expressed, during the process of Metabolism* the upbuilding process (Anabolism) is outweighed by the breaking-down process (Katabolism), the body wastes away and finally dies.

Senile decay and natural death are nothing but the expression of the excess of katabolic changes in the body over anabolic changes.

(b) REGENERATION.

In addition to these phenomena of life and growth, where a process of what may be called physiological regeneration is involved, we find the organism endowed with a still greater power—that of regenerating whole parts of the body under exceptional circumstances.   It is this capability to replace lost parts of the body *in toto* which is generally comprised under the name of Regeneration proper.

It is a well-known fact of daily life that a wound heals ; a defect in the skin, due to an accident, is rapidly repaired. What is this healing process ?   Nothing but a process of cell-regeneration, akin to the one described above.   What happens is this : The cells in the neighbourhood of the injury are stimulated to activity ; they propagate, multiply, and speedily fill up the gap with young cells, each kind of cell regenerating its own kind.   This, within certain limits, is the process involved, whatever may be the part of the body concerned—within certain limits only, because the repair is not always complete.   The higher the organism, the greater the differentiation of its cells, the less capable these become, after completely attained growth in the adult body, to reproduce themselves in mass.   The possibility of regeneration depends largely on the organization attained by the species concerned.   It is for this reason that we find the phenomena of regeneration exhibited to

* Metabolism is the process of assimilation in the body, by which the food taken into the body is changed and worked up into the organic substance of the cell.

the fullest extent among the lower animals. Here not only small tracts of particular tissues can be renewed, but whole parts of organs of the body. The most familiar example is perhaps the well-known case of the lizard, which easily re-grows its broken-off tail ; or of the triton, which will replace a whole leg that has been lost. The crab has the power of growing a new claw in place of that lost in a fight with its rival, one kind actually snapping its own leg when caught. The snail is able to renew its eye, together with the eye-bearing horn. Still lower in the scale, we find the star-fish adding an arm that has been lost, or the sea-cucumber its ejected viscera.

(c) ARTIFICIAL DIVISION.

But we are not yet at the end of the regenerative power of Nature. Besides the accidental losses enumerated above, which are easily made good again, we may go farther, and actually divide some animals into several pieces without any detriment to their existence. On the contrary, the separated parts live on, re-create the missing parts, and become fully-equipped individuals once more. Instead of a loss of life, we have a multiple gain of it.

Of these cases the most familiar example is the common earthworm, which, when divided by the spade, grows into two complete animals, each divided part regenerating the missing portion of the body. The hydra-polypes, the sea-anemones, the Planaria worm, may be cut into many pieces, and each piece will grow again into a new complete individual. To take cuttings and slips from plants is a very common device of the gardener for multiplying his stock. Even the smallest particle of a Begonia leaf will grow into a complete plant again.

We have thus reproduction of parts of the organism up to any extent, the remaining cell-complex always making up the missing part by vigorous multiplication. After all, it is not more wonderful that the same cells which grew, let

us say, into a limb during the individual development of the
embryo should be able, if need be, to perform the same
feat again.

When we come to such cases as the Begonia leaf, where
we find the tiniest particle will reproduce the whole plant,
we are not very far from reproduction proper.   Regenera-
tion may be said to be reproduction of a part of the body,
while reproduction proper is of the whole body.

Now, we have seen that Regeneration itself is nothing
else than new growth proceeding from the old cells, and
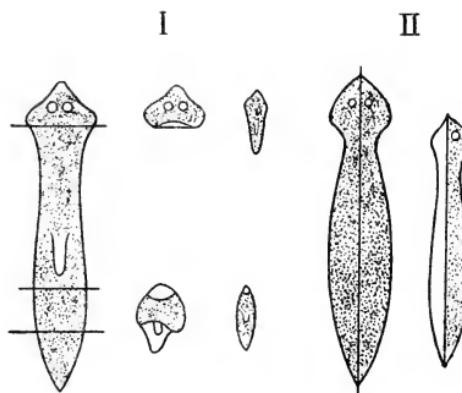
FIG. 2.—REGENERATION OF A PLANARIAN.   (After Morgan.)
(*From Weismann, " The Evolution Theory."*)
I, transverse ; II, longitudinal section.

there will therefore at this stage of our inquiry be nothing
startling in the statement of Herbert Spencer that " Re-
production is discontinuous growth."

This will be still better understood after studying repro-
duction itself in all its phases.

II.—REPRODUCTION.

It was pointed out at the beginning of this chapter that
the first misunderstanding to be cleared up with regard to
reproduction is the popular idea that reproduction means

sexual mating. This will at once become apparent from
the fact that there are numerous classes of low organisms
which are sexless, and in which reproduction can accord-
ingly only be asexual. The only element discernible in the
process of reproduction is here clearly nothing else than
the propagation of the species.

A. Asexual Reproduction.

If we now turn to the cases of asexual reproduction, we
find them chiefly among the lower classes of organisms. It
is the ordinary method of propagation among the one-celled
plants and animals. But it is by no means restricted to
them, as we find asexual reproduction as high up in the
animal kingdom as the worms and tunicates (sea-squirts),
and as a regular occurrence in the branching of flowering
plants.

We can distinguish three kinds of asexual reproduction :
(a) Division ; (b) Budding ; and (c) Sporulation.

(a) Division.

The simplest process of Division we find in the one-
celled organisms. Here—as, e.g., in the Amœba or In-
fusorian—we have a single cell, which, after attaining a
certain size, divides into two daughter-cells. This process
starts with the nucleus, which elongates, becomes dumb-
bell-shaped, and finally breaks up into two halves. The
contents of the cell-body follow suit, become indented, and,
by surrounding the two newly-formed nuclei, bring about
the formation of two separate individual daughter-cells.
This process of division, which is called " Amitosis," shows
clearly that reproduction as just described is nothing but
the outcome of growth. The single mother-cell, becoming
too large for carrying on the process of nutrition, simply
splits up into two constituent halves, which, as it were, are
a continuation of its own existence.

This process of simple fission is the most common method of propagation among the Protozoa and Protophyta, but it can also be observed in species of higher organization, even as high up as the worms.

So we find among the Polypes some which multiply by division ; the newly - formed individuals, however, do not separate, but remain attached to each other, thus forming what is called a Polype - stock.
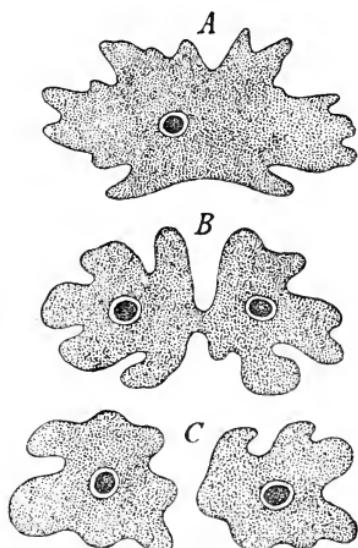
FIG. 3.—DIVISION OF AMŒBA.

(*From Weismann, " The Evolution Theory."*)

A, before division ; *B*, the nucleus divided ; *C*, the daughter amœbæ.

Among the worms, we have the Bristle-footed worm (*Chætopoda*), which, either on a shock or normally, breaks up automatically into several pieces. The sea-worm *Myrianida* forms, when dividing, a whole chain of young worms. In both these cases it is evident that after the division of the mother-animal the completion of the daughter-worms must take place by regenerating the missing portion of the body, either fore- or hind-end, or both. Here, too, we can still trace the close connection between the process of reproduction on the one hand and that of growth and regeneration on the other.

(b) Budding.

While in division, as just described, the whole mother-organism enters into the formation of the respective parts of its progeny—the parent-animal thus being lost in, or rather merged into, its own descendants—in budding the

new offspring takes its origin only from a relatively small part of the mother-organism. The entity of the mother-organism thus remains unimpaired and distinct from the daughter-organism. It is at this stage that we can speak for the first time of a parental relationship between the generations, seeing that we have the parent originating the
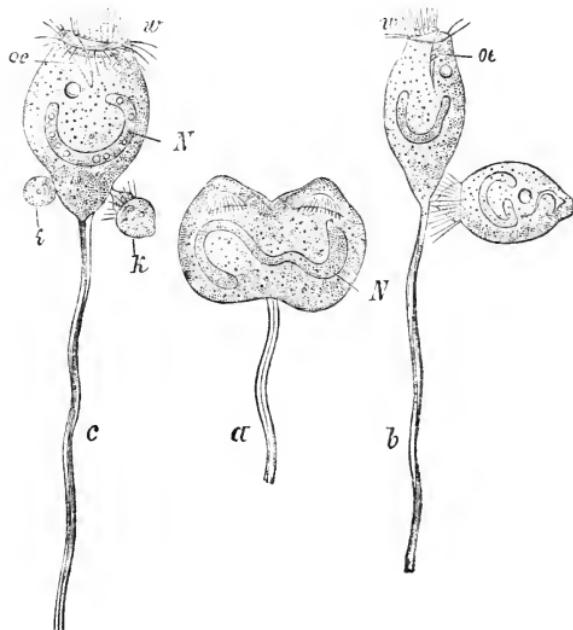
FIG. 4.—VORTICELLA MICROSTOMA. (After Stein.)

(*From Claus, " Textbook of Zoology.*")

a, division ; *b*, division completed ; *c*, conjugation with small attached individual (*k*) ; *N*, nucleus ; *oe*, gullet ; *w*, cilia.

offspring from a part of its own body leading to a distinct and independent existence of the same. Yet, as can be seen at a glance, the original connection with mere physiological growth of the body is still a very close one. The parent body, whilst in the process of growing, bulges out its contents at a particular point, and the " bud "

thus formed becomes the starting-point of the new off-spring.

The common yeast (a one-celled plant organism) is a very typical example.

Budding as a means of reproduction is more frequent than division, and can be found in all lower classes of animals, right through the Sponges, Corals, Polypes, etc., up to the Worms and Tunicates.

Very often the new individuals arising from the buds do
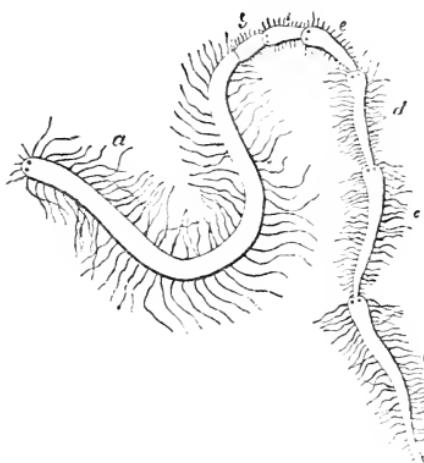
FIG. 5.—DIVISION OF MYRIANIDA, A MARINE WORM.   (After Milne-Edwards.)

(*From Weismann, " The Germ-Plasm."*)

a to *g*, the daughter-individuals according to their relative ages.

not separate from the parent body, but, remaining attached to it, and budding off further individuals in all directions, form a ramifying conglomeration of animals, the animal-stock.

Typical examples are the Sponges, Corals, and Hydra-polypes.   Something similar can be seen in the marine worm *Syllis ramosa*.

Among the higher plants reproduction by budding is a
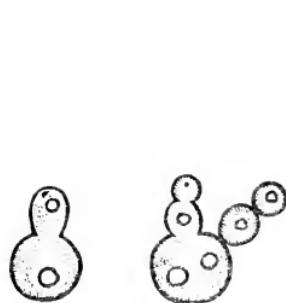
FIG. 6. — BUDDING OF YEAST. (After Prantl.)
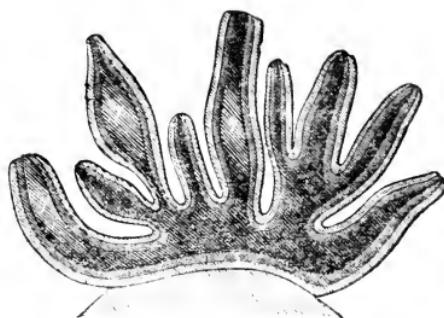
FIG. 7. — BUDDING OF SPONGE COLONY. (After Haeckel.)

(*From Geddes and Thomson, " The Evolution of Sex."*)
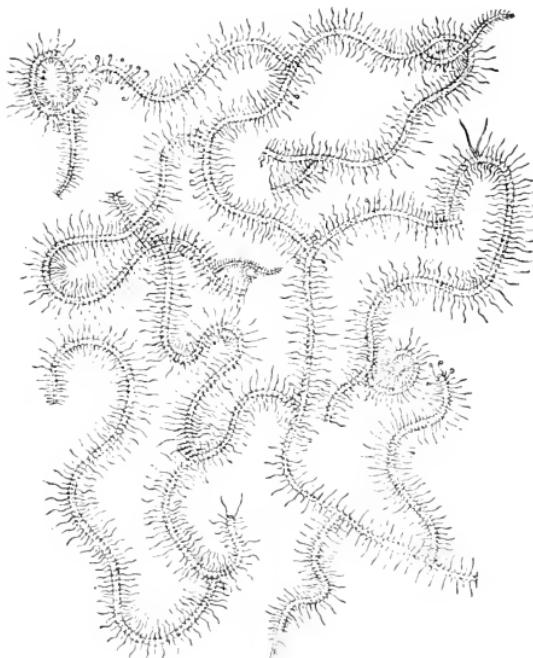
FIG. 8.—BUDDING OF SYLLIS RAMOSA, A MARINE WORM.
(*From Geddes and Thomson, " The Evolution of Sex."*)

regular occurrence.   In fact, all the flowering plants pro-
pagate, in addition to the sexual way by budding, by means
of flowers and seed, in an asexual manner ; for every shoot
and branch of the plant must be looked upon as a distinct,
asexually produced individual.   In reality, a flower-bearing
branching plant is to be compared to the ramified animal-
stock ; it is, indeed, a multiple individual, a " plant-stock."

(c) Sporulation.

In sporulation we have special cells of the body set aside
for reproduction, which, after detaching themselves from
the mother-organism, produce the new progeny.   These
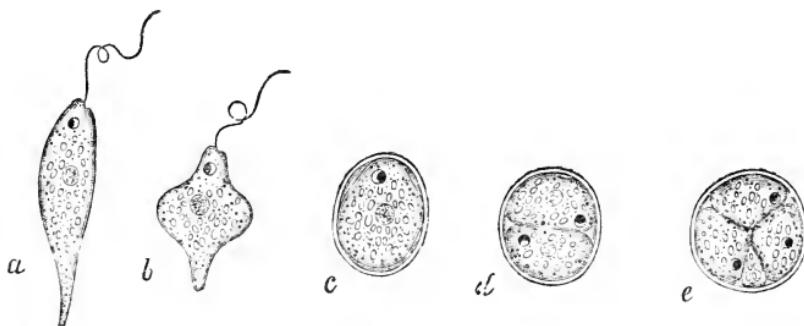
FIG. 9.—EUGLENA VIRIDIS.

(*From Claus, " Textbook of Zoology."*)

a and *b*, free, swimming, in different states of contraction; *c* to *e*,
encysted and in process of division.

cells may already be called germs in the proper sense, but
they differ from the real germ-cells in this respect—that
they are sexless.

Sporulation is chiefly to be found among the lower plants
—Algæ, Mosses, Ferns, etc.—and in a few kinds of Protozoa.
In some cases—as, *e.g.*, in the Infusorian *Euglena*—the
whole contents of the original organism, after becoming
encysted, break up into a mass of spores, which, bursting
the mother-shell, swarm freely about as the new young
individuals.

B. Conjugation.

Conjugation, which means the union of two separate individuals for the purpose of propagation, gives us the true connecting-link between asexual and sexual reproduction. The transition between them is very gradual—so much so that we may trace every stage from the union of two organisms completely alike in every respect up to the
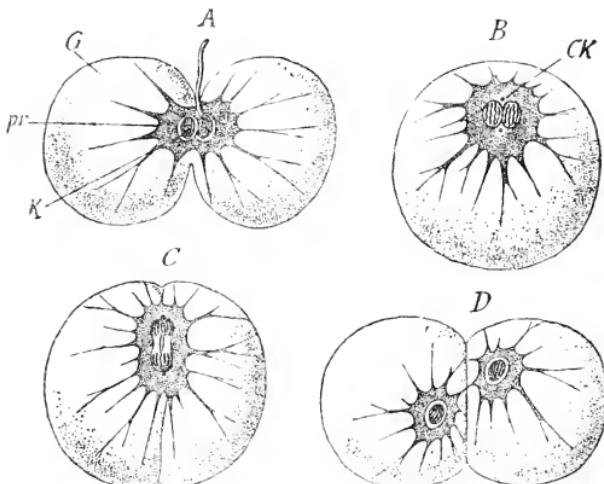
Fig. 10.—Conjugation of Noctiluca. (After Ischikawa.)

(*From Weismann, " The Evolution Theory."*)

A, two individuals coalescing ; *B*, fusion of cells ; *C*, beginning of division ; *D*, completion of division ; *pr*, protoplasm ; *K*, nucleus ; *G*, cell-body ; *CK*, centrosome.

true sexual mating of distinct male and female in the higher animals.

We have, to begin with, two (or rarely more) individuals of the species (as in Algæ or Infusorians) simply mingling their combined bodies into one, and thereafter multiplying by simple division in the ordinary manner. In the Bell-animalcule (Vorticella), mentioned once before, conjugation takes place between the large mother-animal and one of the much smaller progeny, which has resulted from re-

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peated divisions (see Fig. 4, *c*); in the Alga *Zanardinia* the two conjugating cells are already of widely divergent character, approaching in type the bulky female and minute active male germ.

Further, that conjugation means more than mere fusion and consequent separation of the cell-substance of the two individuals concerned can be seen in those cases where, as in the Infusorian *Paramaecium caudatum,* an exchange of nuclei can be clearly demonstrated between the two conjugating animals. The two bodies, after closely approximating to each other, send each a nucleus across to the other. Evidently the purpose of conjugation seems to be the mixture and exchange of the qualities of the two parents and their redistribution among the offspring. We can, therefore, regard this process as the last link leading up to real "Amphimixis"—*i.e.,* the mixing of parental qualities for the production of progeny.

FIG. 11. — CONJUGATION OF ZANARDINIA. (After Reinke.)

(*From Delage*, "*Hérédité.*")

a, female ; *b,* male; *c,* conjugation ; *d,* product of conjugation.

C. SEXUAL REPRODUCTION.

It has become evident from what has gone before that amphimixis, or the co-mingling of the sexes, is *not* the essential element in the process of reproduction. Reproduction, which, as we have seen, can be carried on by a single individual, and is only gradually delegated to two differentiated sexes, has the one object—that of the

FIG. 12.—CONJUGATION OF PARAMÆCIUM. (After Hertwig and Maupas.)

(From Weismann, "The Evolution Theory.")

1, two individuals apposed; 2, each nucleus divided into two daughter-nuclei; 3, each daughter-nucleus divided once more into two; 4, the resulting four nuclei in each animal; 5, three of these divided nuclei (mi^3) dissolve, the fourth (mi^4) divides once more into two; 6, one of each of these divided nuclei ($mi\,\delta$) migrates into the other animal, forming with the remaining nucleus ($mi\,\female$) 7, the conjugation-nucleus ($copk$); 8, separation of the two conjugating animals; 9, final formation of the nuclei, which now contain both parental qualities combined.

propagation of the species. We must, therefore, look upon this as the main function of sexual reproduction also.

We may conveniently deal with sexual reproduction under four heads : (*a*) Heterogamy ; (*b*) Autogamy ; (*c*) Parthenogenesis ; and (*d*) Alternation of Generations.

(*a*) *Heterogamy.*

Heterogamy means reproduction by union of differentiated male and female individuals. This is, of course, the best known, because made familiar to us by its occurrence in all higher animals and man. Here we have the union of the separate male and female organisms, in order to produce the new progeny. Among the Protistes, as described under Conjugation, the fusion takes place bodily ; but with Metazoa and Metaphyta this would evidently be impossible. Now, we have seen already in the evolution of asexual reproduction that distinct parts of the body may be set aside for the purpose of propagation, as in sporulation, where the spores may be looked upon as asexual germ-cells. A similar process of differentiation between body and propagating germ-cells takes place among the Metazoa. We can see this illustrated beautifully in the *Volvox*, which may be described as a cell-colony of one-celled animals. Here some of the uniform body-cells become distinct from the others, and develop into sex-cells, these alone being able to reproduce the species.

FIG. 13.—VOLVOX MINOR. (After Stein.)

(*From Weismann, " The Germ-Plasm."*)

sz, body cells ; *kz*, germ cells.

As the ultimate outcome of this process we find, on the one hand, a parent-organism, and within the body of that parent definite cells—the germ-cells—from which the development of the new progeny takes its origin. In the highest form each parent organism forms germ-cells of a
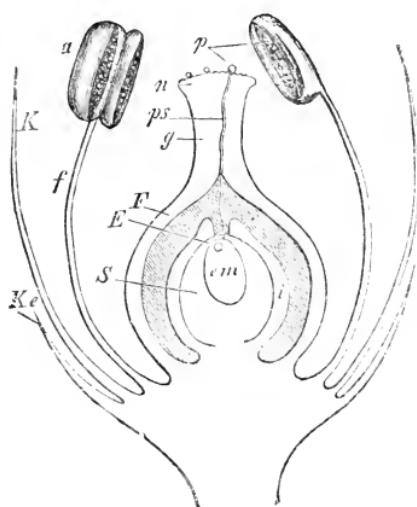
FIG. 14.—DIAGRAM OF A FLOWER.
(After Prantl.)

Ke, calix ; *K*, corolla ; *f*, stamen ; *a*, anther with pollen (*p*); *F*, ovary; *g*, pistil ; *S*, ovule ; *em*, embryo sac ; *i*, integument of ovule.
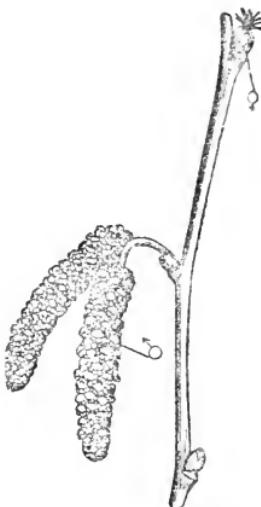
FIG. 15.—CATKINS OF HAZEL.

(*From Oliver, " Elementary Botany."*)

♂ male ; ♀ female flowers.

definite kind, either male or female, the union of both these germs being essential for the procreation of the new generation.

Among plants we find male and female germ-cells in all flowering species—the former, the pollen-grain, being developed in the anther of the stamen of the flower ; the latter, the ovule, lying in the ovary, to which the pistil leads. Most flowers possess both sexual organs, stamen as well as pistil ; but many flowers are uni-sexual, having either

stamen only or pistil only.   When uni-sexual flowers of both kinds, male *and* female, are to be found on the same plant, the plant is said to be " mon-œcious " (as oak, alder,
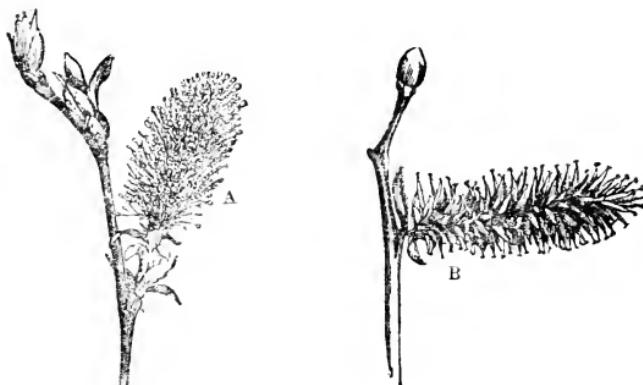
FIG. 16.—CATKINS OF WILLOW (SALIX).
(*From Oliver, " Elementary Botany."*)
A, male ; B, female.

hazel) ; when male and female flowers are on different plants, such plants are " di-œcious " (as in the willows).

Copulation.

In order that the germ-cells, male and female, may reach each other, the most varied contrivances exist in Nature. Darwin has described most wonderful adaptations of flowers for the purpose of attaining fertilization, either by the agency of the wind or of insects.

In the animal kingdom the means of bringing together male and female germ-cells, which here are called sperma-tozoon and ovum respectively, are in the lower classes of extreme simplicity.   The liberated sex-cells meet each other in a random manner, brought together by water-currents, etc., either within the body-cavity (sponges) or outside it (as in the sea-squirts).   There is, it is true, a subtle chemical attraction between the generative elements,

but only when in close proximity, so that external union is largely left to chance. It is only when we ascend higher in the scale of organization that special precautions are taken to insure the safe union of both sex-elements. Thus the male cuttle-fish (*Argonauta*) discharges one of his modified arms filled with spermatophores (packets of spermatozoa) bodily into the cavity of the female, where it bursts. The female fish lay their eggs, closely followed by the attracted males, who thereupon fertilize the eggs with their sperm. A further step in this direction is made by the frog. Here fertilization is still outside the body of the mother - animal, but the male, embracing the female, liberates the spermatozoa directly on the eggs as they are laid. Final security is reached by the act of copulation proper, where nothing is left to chance. Special organs exist

FIG. 17.—- MALE OF CUTTLEFISH (AR-GONAUTA) WITH MODIFIED ARM.

(*From Geddes and Thomson, " The Evolution of Sex.*")

in the female to receive the sperm, in the male to introduce it into the female sexual organs, where the ovum is ready to unite with it in order to accomplish the act of fertilization.

(b) *Autogamy.*

While in Heterogamy we have the union of two distinct individuals—that of a male with a female—in Autogamy the organism, as it were, mates itself, both kinds of sex-cells being present within the same individual. Such indi-

viduals, being male and female at the same time, are known as " Hermaphrodites."

Hermaphroditism is, as already mentioned above, a very common occurrence in flowering plants, most flowers containing pistil as well as stamen.

In animals it is less frequent, but by no means rare. It occurs normally in Sponges, Corals, Worms, Snails, etc. Even the higher animals, including man, pass through a fœtal stage when both sex-organs, male and female, are still existent ; but only one of them in the course of development reaches its full form and function. As a pathological curiosity, this embryonic stage may persist in the adult.

We find that even when both kinds of germ-cells are present in the same individual self-fertilization is by no means the rule. On the contrary, as Darwin has shown in plants—and something similar holds good for animals— most ingenious contrivances are set up to insure cross-fertilization—*i.e.*, fertilization of one individual by another.

(c) *Parthenogenesis.*

Parthenogenesis, which was discovered in 1745 by Bonnet in the plant-lice, is the power which certain female animals possess of producing offspring without sexual union with the male—*i.e.*, without fertilization.

The case of the bee is a well-known example of partial Parthenogenesis. The queen-bee, who is impregnated only once in her life—during her nuptial flight—lays two kinds of eggs : one kind, which are fertilized by the queen-bee with the stored-up sperm, become workers or a queen, while the other kind, not fertilized, become drones. Seasonal Parthenogenesis is to be found among water-fleas (minute aquatic Crusters—*Cladocera*) and the plant-lice, or *Aphides*. Here we have a succession of virgin-births during summer, but males generally reappear towards autumn, and with them the ordinary sexual reproduction.

Lastly, in some minute aquatic Crusters and many Rotifers (water-worms) no males have ever been found. Propagation must, therefore, take place altogether without males, thus giving us the phenomenon of total Parthenogenesis.

Seeing that parthenogenetic reproduction is by no means rare, and that the number of such offspring is abundant, it becomes once more evident from these facts that sexual union is by no means essential for the propagation of life.

(d) *Alternation of Generations.*

We have just described the occurrence of parthenogenetic females in plant-lice during summer which alternate with the sexual generation of males and females of the autumn. As the summer breeds differ from the autumn breeds, we have here a true case of alternation of generations. In the cited instance sexual generations alternate with parthenogenetic ones. But the succession may be between sexual and asexual generations, the latter propagating by division, budding, or sporulation.

The former case is illustrated by the Hydra-polypes and the common jelly-fish (Aurelia). In both these instances we find free-swimming sexual individuals producing a sessile generation, which is asexual, and
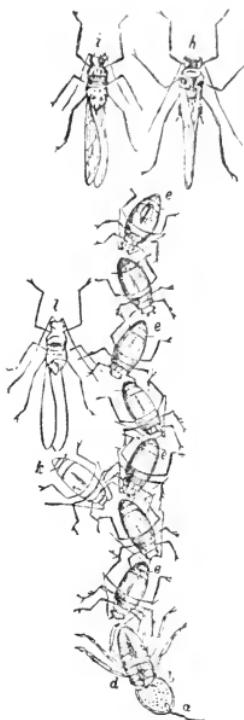
FIG. 18.—ALTERNATION OF GENERATIONS IN PLANT-LICE.

(*From Geddes and Thomson, " The Evolution of Sex."*)

At the base is an individual arising from a fertilized egg-cell ; this gives origin parthenogenetically to a succession of generations. At the top are shown the male and female forms, which ultimately reappear. At the side an earlier reappearance of sexual forms is suggested.

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produces in its turn, either by division (*Aurelia*) or by budding (Hydrapolype), once more the sexual free-moving generation.

The interpolation of asexual reproduction by spores between sexual generations is a well-studied phenomenon
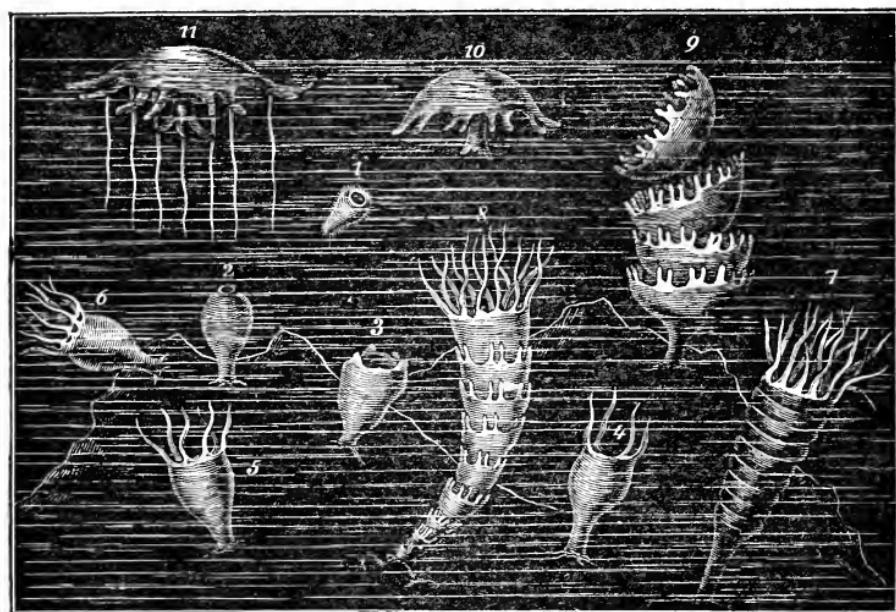
FIG. 19.—ALTERNATION OF GENERATIONS IN THE COMMON JELLY-FISH (AURELIA). (From Haeckel.)

(*From Geddes and Thomson, " The Evolution of Sex."*)

1, free-swimming embryo ; 2, embryo settled down ; 3 to 6, the developing asexual stage ; 7 and 8, the formation of a pile of individuals ; 9, their liberation ; 10 and 11, the free-living sexual form.

among lower plants. In the ordinary Fern we have the big fern-leaf, the asexual plant, producing the familiar spores at the back. These develop when in suitable ground into an inconspicuous green organism, with male and female sex-cells. From the union of both arises once more the tall fern-plant. In the Moss we have a similar process, but

in this case the sexual plant is the more conspicuous one. The higher flowering plants all exhibit a sort of alternation of generations, inasmuch as the plant first throws off branches—*i.e.*, individuals arising by the asexual process of budding—which in their turn produce sexual flowers. But here the sexual generation never becomes really independent, remaining more or less a part of the asexual organism.

CHAPTER III

THE GERM-CELLS

I.—HISTORICAL.

NOTHING will be more helpful towards a right appreciation of the fundamental facts of our subject than a proper understanding of their historical relationship. One is apt to become impatient when lost in a tangle of dark and unknown paths, leading, it seems, nowhither—and the science of Heredity often leaves us in such a maze ; but it would be wise to take into consideration, not what has still to be achieved, which is much, but what has already been attained, which is not little. We shall find that nearly our whole knowledge of the subject is of very recent date indeed, and shall therefore be less surprised to find that so many problems of this most important branch of human inquiry are still unsolved.

For one who is accustomed to look upon biology from the modern point of view, it is nearly an impossibility to revert to the state prevalent at the time when the cell as the unit of the organism was unknown. And yet it was only in 1838 that Schleiden for the first time demonstrated the cell-structure of plants, showing that plants were not only built up of cells, but also took their origin from a single cell, the ovum. The same was proved by Schwann in the following year, 1839, to apply to the animal kingdom. Up to then cells had occasionally been seen with the microscope, but, as the name implies, they had been looked upon as " cells "—*i.e.*, cavities filled with air. Only gradually were they recognized to be solid bodies having contents,

protoplasm and nucleus.   It was only after the discoveries
of Schleiden and Schwann, and the application of the cell-
theory to the whole range of biological facts, normal as well
as pathological, that a real science of life became possible.

This being the case with biological science in general, it
is not astonishing that the same applies with even more
force to the science of Heredity.   The latter can, indeed,
be said to date in reality only from the time of the dis-
covery of the cell-nature of both sexual germs, the ovum
and spermatozoon.

The chick had gradually been traced back (by Harvey
1651, Malpighi 1672, and others) to its real starting-point—
the vital part within the hen's egg ; but it was as late as
1828 that Von Baer discovered the ovum of the mammals.
It was much later still—in 1861—that the German zoologist
Gegenbaur finally demonstrated the fact that the egg of
every vertebrate is a single cell, the same being subse-
quently shown to hold good for that of invertebrates and
plants also.

The male sex-element of the higher animals, not being
permanently hidden within the body, as is the egg-cell, was
discovered very much earlier—in 1677.   But here the
central fact was at first missed altogether : the seminal
fluid was thought to be the important element, while the
spermatozoon was looked upon, as the name implies, as
a parasitic animalcule.   It was only much later that the
presence of spermatozoa was found to be the essential
factor in fertilization, and only in 1841 did Kölliker demon-
strate its cellular origin in the male sex-glands, the testes.

II.—THE GERM-CELLS.

It is, then, a fundamental fact that both germ-cells, the
ovum as well as the spermatozoon, are single cells, pos-
sessing all the qualities of such, and behaving in their
fundamental functions like cells.   These we are now going
to study more in detail.

(*a*) Karyokinesis.

We have already explained that each cell possesses a nucleus, which is the most important part of the cell. This nucleus has a limiting membrane, and is filled with a network of a substance called " Linin," while on this network is arranged the " Chromatin," so called because it is easily colourable with artificial stains. On this chromatin has been centred the greatest interest, because it is the substance which has to be looked upon as the bearer of the hereditary qualities of the cell, and therefore of the organism. Apart from other arguments, which will appear later, this becomes evident from the rôle the chromatin plays in the division of the cell. This division, which goes by the name of " Mitosis," or " Karyokinesis," takes place in a most regular and exact manner, and serves the purpose of dividing the chromatin substance into two equal parts.
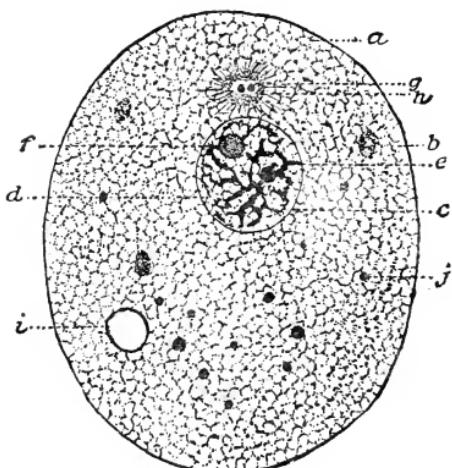
Fig. 20.—A Cell.

(*From H. W. Conn, " Story of Life's Mechanism."*)

a, protoplasmic network; *b*, liquid in its meshes; *c*, nuclear membrane; *d*, nuclear network; *e*, chromatin network; *f*, nucleolus; *g*, centrosome; *h*, aster; *i*, vacuole or airspace; *j*, inert bodies.

Starting with the resting phase of the cell, before it begins to divide, we see the arrangement of the nucleus with its chromatin, as just described, and in it a little body, the " Nucleolus," the function of which has not yet been elucidated. Just outside the nucleus lies the small
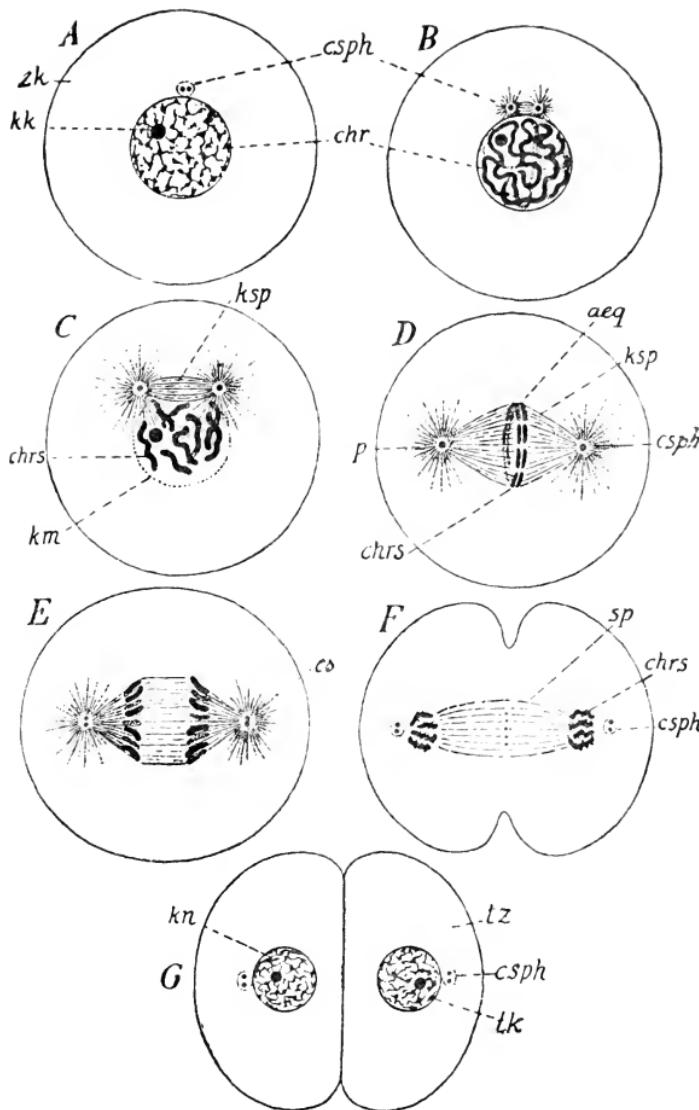
FIG. 21.—KARYOKINESIS. (Adapted from E. B. Wilson.)

(From Weismann, " The Evolution Theory.")

A, resting-phase; *B*, chromatin (*chr*) in coiled thread; *C*, eight
chromosomes (*chrs*) and two asters formed; *D*, chromosomes
split and lying in equatorial plane, the two centrosomes (*csph*)
at the poles; *E*, chromosomes separate; *F*, division of cell-
substance; *G*, final formation of two daughter-cells; *zk*, cell-
substance; *kk*, nucleolus; *km*, membrane of nucleus; *aeq*, equa-
torial plane; *ksp*, radiating fibres.

" centrosome," destined to play an important part in the process of division.

The first stage of the division is initiated by a rearrangement of the chromatin into a long thread, which immediately breaks up into a number of small pieces, called the " Chromosomes." The number of these chromosomes is the same for all ordinary cells of the organism, and does not vary within any given species. At the same time, the centrosome, which lies just outside the nucleus, has divided into two, each new centrosome becoming surrounded by radiating fibres, which give it a starlike appearance ; hence the name " aster." The centrosomes now separate, each wandering through a quarter of a circle into the opposite direction, the radiating fibres stretching between them. There seems to be no doubt that the centrosome, with its asters, exerts the determining influence in the division of the nuclear contents. Meanwhile the limiting membrane of the nucleus has disappeared, and the chromosomes have arranged themselves in the equatorial plane between the two asters. The next step effects the halving of the chromosomes. Each of the chromosomes splits up, not across the middle, but *lengthwise*, so that instead of each single chromosome we get now a pair of them lying alongside each other. We have, therefore, at this stage a double set of chromosomes, one lying close to the other in the equatorial plane. These two sets next separate from each other by moving to the opposite poles towards the centrosomes, each set thus forming a new daughter-nucleus. Finally, the chromosomes lose their threadlike appearance, form again a network, and surround themselves with a new membrane. As, meanwhile, the cell-substance also has divided, we have at last two complete daughter-cells, each exactly the same as the mother-cell with which we started. We see, in fact, that this process of division effects the exact halving of the chromatin substance, so that each daughter-cell receives not only the same number, but also the same kind of chromosomes as the mother-cell had.

(b) Ovum.

Coming now to the description proper of the germ-cells, we shall start with the Ovum.

The ovum is a cell, and has as such the typical cell-structure. It has a cell-body, limited by a cell-membrane,
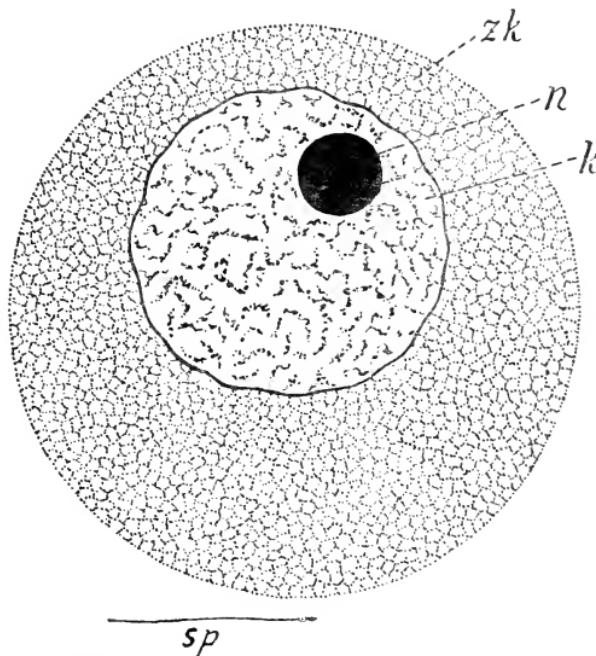
Fig. 22.—Ovum of Sea-Urchin, Toxopneustes Lividus. (After Wilson.)

zk, cell-body ; k, nucleus ; n, nucleolus. Below the ovum the spermatazoon (sp) of the same animal is drawn with the same magnification.

and, further, a nucleus, here called the " germinal vesicle," which again contains the nucleolus and the chromatin substance.

The size of the ovum varies considerably. It is often microscopical, as in the mammalian eggs, but can attain, on the other hand, enormous proportions, as in the case of birds. The essential part of the egg-cell, however—the

nucleus—is always small, generally visible only with the
aid of the microscope, the remainder of the egg being
made up by various extrinsic additions, but chiefly the
yolk. The latter is material stored up within the egg to
serve the forthcoming embryo as nourishment. We can
see how the large size of the bird's egg, *e.g.*, is mostly made
up by the yolk, which lies around the very minute germinal
vesicle.
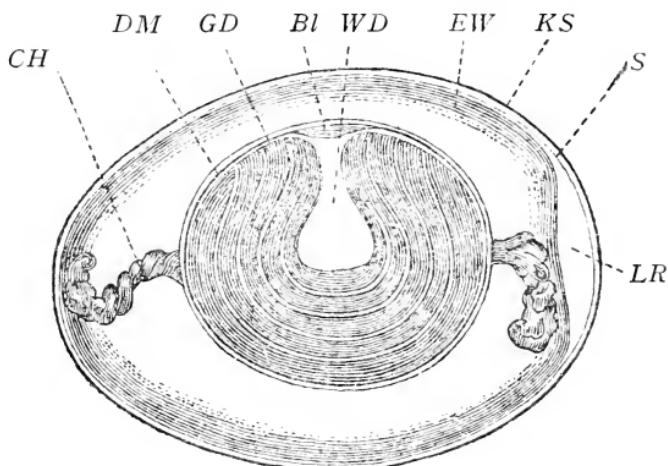
FIG. 23.—HEN'S EGG : DIAGRAMMATICAL LONGITUDINAL SECTION.
(After Allen Thomson.)

(*From Weismann, " The Evolution Theory."*)

CH, chalaza ; *DM*, vitelline membrane ; *GD*, yellow yolk ; *Bl*, ger-
minal disc with germinal vesicle ; *WD*, white yolk ; *EW*, albumen ;
KS, shell ; *S*, shell membrane ; *LR*, air-chamber.

According to the disposition of the yolk within the egg,
we distinguish four types of eggs, each of which is charac-
terized, as we shall see later, by a typical method of seg-
mentation. We have eggs with (1) diffuse yolk, where
there is a small amount of yolk evenly distributed through-
out the egg-cell, as in Invertebrates (Sponges, Corals, Star-
fish, Worms, etc.), and Mammals ; (2) central yolk, the
yolk being in the centre of the egg, as in Arthropods

(Crusters, Insects) ; (3) polar yolk, a large proportion of
yolk, accumulated chiefly in the lower half of the egg, as in
Amphibians (Frog) ; and finally (4) predominant yolk,
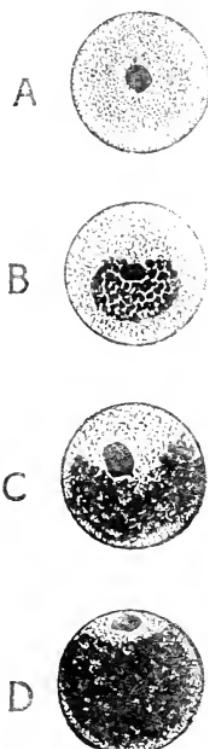
FIG. 24.—OVUM AND DISPOSITION
OF YOLK.   (After Thomson.)

A, ovum with diffuse yolk (sponge) ;
B, ovum with central yolk (cray-
fish) ; *C*, ovum with polar yolk
(frog) ; *D*, ovum with predomin-
ant yolk (bird).

FIG. 25.—SPERMATOZOON.
(After Wilson.)

(*From Weismann, " The
Evolution Theory.*")

sp, point ; *n*, nucleus ; *c*,
centrosome ; *m*, middle-
piece ; *ax*, tail.

where nearly the whole egg is taken up by the yolk except
a tiny part at the upper pole of it, as in Fishes, Reptiles,
and Birds.

(c) Spermatozoon.

The Spermatozoon is, as a rule, very much smaller than the corresponding ovum. Its form is adapted to its function, for it actively seeks and penetrates the ovum.

The typical spermatozoon—as, *e.g.*, in man—consists of a small pointed head, composed nearly entirely of the nucleus, a middle piece, containing the centrosome, and a long contractile tail, by means of which the spermatozoon
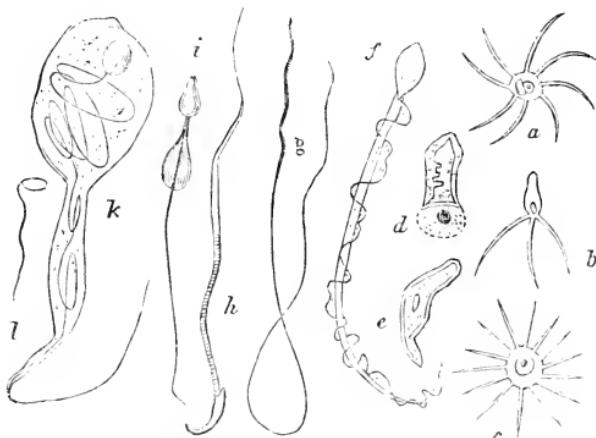
Fig. 26.—Spermatozoa.

(*From Geddes and Thomson, " The Evolution of Sex."*)

a, crayfish ; *b*, lobster ; *c*, crab ; *d*, ascarid ; *e*, water-flea —*moina* ; *f*, man ; *g*, ray ; *h*, rat ; *i*, guinea-pig ; *k*, beetle—immature stage ; *l*, sponge.

effects its rapid undulatory movements. The shape in other cases may differ, be starlike or clublike, but the active amœboid movements are an essential feature of it.

III.—MATURATION.

Both germ-cells, ovum as well as spermatozoon, possess the same number of chromosomes as the ordinary body-cells, which, as has already been remarked, is constant for

any given species. Before, however, the germ-cells are ready to unite in the act of fertilization, they undergo certain changes, which have the effect of leaving them with only half the number of chromosomes they had previously. This process in the ovum is called its " maturation," while the same end is achieved for the spermatozoon during its development—*i.e.*, during the process of spermatogenesis.

(a) OVUM.

In 1875 Bütschli showed that the small polar bodies, which had been observed outside the ovum as far back as 1824, resulted from the division of the egg-nucleus itself. After it had further been established in 1883 by E. van Beneden for the round-worm of the horse (*Ascaris megalocephala*), and later for most other animals and plants, that the sex-nuclei of ovum and spermatozoon contain only half the number of chromosomes that are characteristic for the cells of the parent-body, the connection between these two phenomena became gradually cleared up, so that Weismann was finally enabled to formulate his own now generally accepted view, that the maturation of the ovum has no other purpose than to effect the reduction of the chromosomes to half their original number.

But this " reducing division " is not so simple as just suggested, because, before the reduction of the chromosomes, a doubling of them first occurs, so that, in order to get ultimately the reduced number, the division has to take place twice.

We have, to take an instance, an egg-cell with four chromosomes before maturation. This egg-cell, as it ripens, grows larger, and doubles its number of chromosomes, having now eight instead of four. Now, in the first instance, half the number of these eight chromosomes —*i.e.*, four—are removed from the mother egg-cell altogether by a process of division, as described above, under

the heading of Karyokinesis. But here there are to be
noted two differences from the ordinary division. Firstly,
the two daughter-cells resulting from the division are of
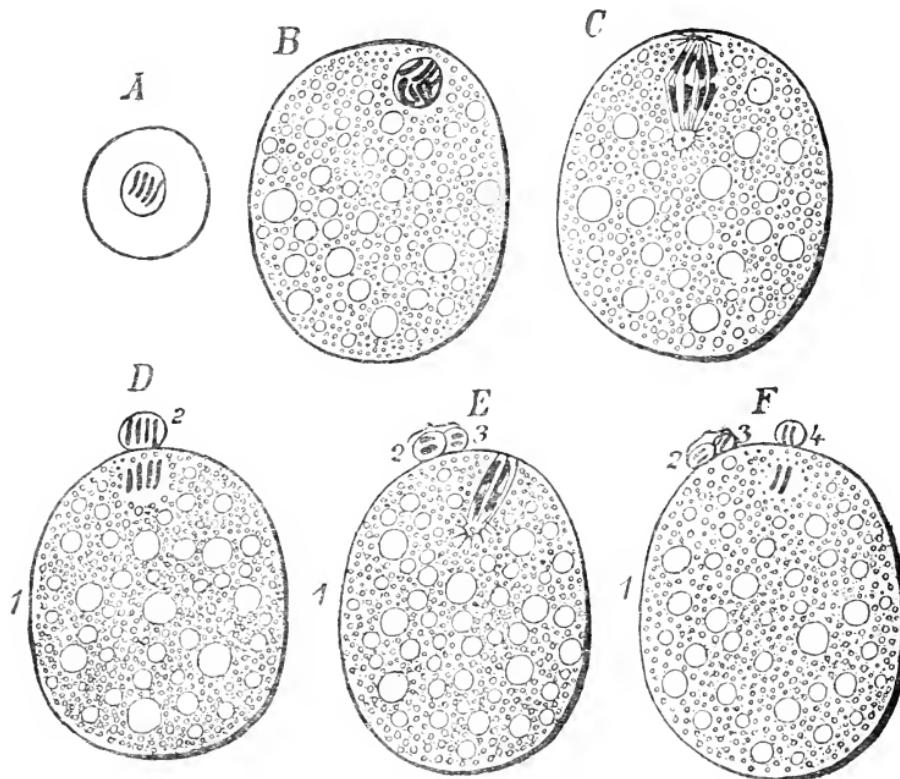
FIG. 27.—MATURATION OF OVUM.

(*From Weismann, " The Evolution Theory."*)

A, primitive ovum with four chromosomes ; *B*, mother-egg cell with
  eight chromosomes ; *C*, first maturation-division ; *D*, formation
  of first polar body (2) ; *E*, second maturation division and
  division of first polar body into two (2 and 3) ; *F*, formation
  of second polar body (4).

very unequal size, the larger one remaining as the ovum
proper, while the smaller one forms the first polar body,
which thus comes to lie outside the ovum. The second

difference is this : that each of the two daughter-cells does
not receive, as happens in the regular Karyokinesis, the
same number of chromosomes as the mother-cell.   Indeed,
no splitting up of the chromosomes lengthwise takes place
for that purpose, but each daughter-cell receives only half
the original number of chromosomes—*i.e.*, in our case, as
the ripe ovum had eight chromosomes, the ovum, as well
as the first polar body, have after the first division four
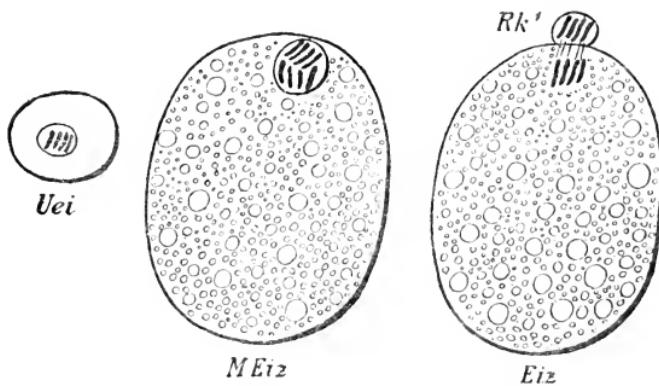
FIG. 28.—MATURATION OF PARTHENOGENETIC OVUM.

(*From Weismann, " The Evolution Theory."*)

Uei, primitive ovum with four chromosomes ; *MEiz*, mother egg-
    cell with eight chromosomes ; *Eiz*, formation of one polar
    body (*Rk¹*).

chromosomes each.   But now a second division is neces-
sary, in order to reduce the number of chromosomes still
further to half the original number of the primitive ovum,
which had four chromosomes.   This takes place in the
same manner as just described for the formation of the first
polar body.   The remaining chromosomes of the ovum
divide again, two now remaining finally in the ovum, and
two forming a new polar body.   As the first polar body
also has meanwhile divided into two, each with two
chromosomes, we have as the final product of maturation
the ovum with two chromosomes (being half of the original

number) ready for fertilization, and three polar bodies, each with two chromosomes. The polar bodies, so far as our present knowledge goes, seem to be functionless, and are lost. The accompanying illustration (Fig. 27) will make the process still clearer.
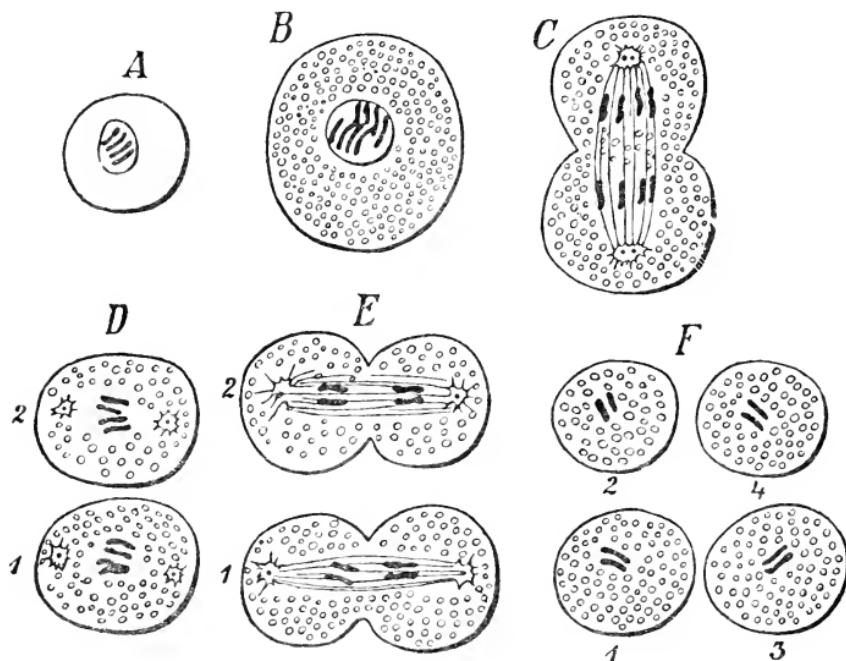
FIG. 29.—SPERMATOGENESIS.   (Adapted from O. Hertwig.)

(From Weismann, " The Evolution Theory.")

A, primitive sperm-cell with four chromosomes ; *B*, mother-sperm-cell with eight chromosomes ; *C*, first maturation division ; *D*, formation of first two daughter-sperm-cells ; *E*, second maturation division ; *F*, final four sperm-cells.

The parthenogenetic ovum, as has now been abundantly proved, divides only once for maturation—that is, it first doubles its number of chromosomes, and then extrudes only one polar body, thus retaining the full original number of chromosomes.

(b) Spermatogenesis.

The observation of the reducing division in the ovum suggested to biologists to look for a similar process in the male germ-cell. This process was actually found to occur,
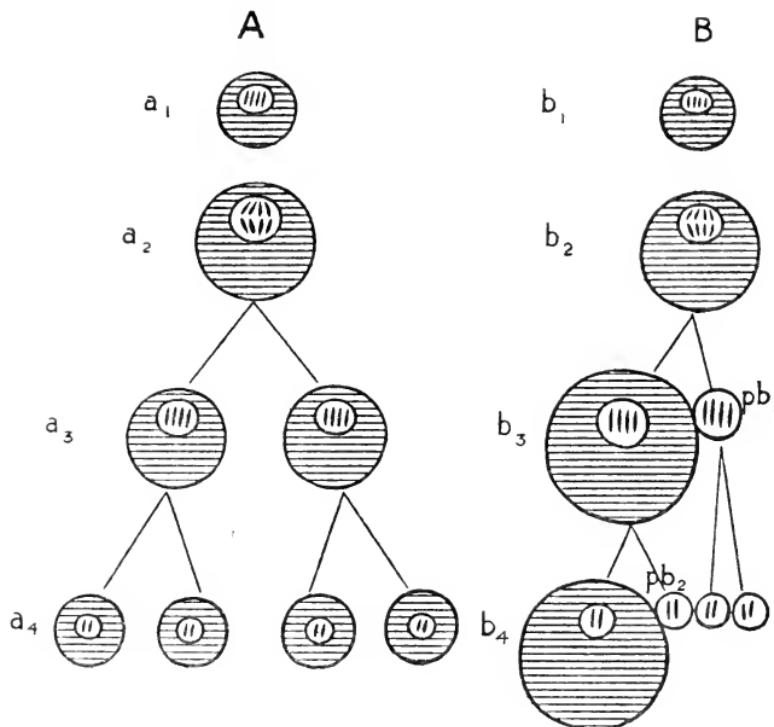
FIG. 30.—SPERMATOGENESIS AND MATURATION OF THE OVUM COMPARED. (After Hertwig, Weismann, and Delage.)

A, *Spermatogenesis.*—a_1, the primitive sperm-cell; a_2, the mother sperm-cell; a_3, two sperm-cells; a_4, four sperm-cells.

B, *Maturation of Ovum.*—b_1, the primitive ovum; b_2, the mother egg-cell; b_3, ovum and first polar body (pb_1); b_4, ovum with second polar body (pb_2), and division of first polar body into two.

but it is here slightly different from the ovum; for while the ovum rids itself of half its chromosomes during its maturation, the halving of the chromosomes in the sperm-

6

cell takes place earlier, during the process of its formation
—*i.e.*, during spermatogenesis. Furthermore, while the
products of the reducing division of the ovum are, as we
have seen, of unequal size, the three small polar bodies
being cast away, in spermatogenesis all the resulting cells
are of equal size, and capable of functioning. Otherwise
the two processes are in every respect alike. We have a
sperm-cell with, let us say, four chromosomes again. As
this cell grows, it doubles its number of chromosomes to
eight. Then this mother sperm-cell goes through a double
reducing division, first splitting up into two daughter-cells
with four chromosomes each, and finally into four grand-
daughter sperm-cells with two chromosomes each. These
are all of equal size, and all function as sperm-cells. They
are the primitive spermatozoa, which soon assume the
proper shape characteristic for each species.

The parallelism will be made quite clear in the adjoined
scheme (Fig. 30).

We must add that in both cases the chromosomes
finally lose their identity, forming a network of chromatin,
as shown in the ordinary body-cells.

IV.—FERTILIZATION.

It is a strange fact that, although the union of both sexes
was thought to be the essential factor in the act of repro-
duction (see Chapter II.), it was a considerable time before
the true import of both male and female germs was
recognized. Two schools—the Ovists and Animalculists—
held sway for a long time in fierce opposition to each other,
the former declaring the ovum as the all-important element
in fertilization, while the other attributed this rôle, with
the same one-sidedness, to the spermatozoon (animalcule).
And even after due credit had been given to both elements
alike, the real meaning of their union was far from being
understood, it being held that a sort of seminal breath
(aura seminalis) passed from the seminal fluid to the

ovum. It was only about 1875, with the recognition of
the cell-structure of the sex-elements, that the correct
interpretation of fertilization was found in the union of the
nuclear substance of the male and female sex-cell.

The spermatozoon (generally only one) as the active
element enters the ovum, which has already gone through
its ripening process, and possesses, to take the same ex-
ample of *Ascaris megalocephala*, as instanced before, two
chromosomes. The nuclear substance of the sperm-cell
then changes its appearance. It becomes pale, grows in
size, and its network of chromatin transforms itself into
two chromosome loops, the same also taking place with the
chromatin of the ovum. Simultaneously the centrosome
introduced with the spermatozoon has doubled (the
centrosome of the ovum generally plays no rôle, and dis-
appears), and forms a double aster ; while the two " pro-
nuclei," as the male and female nuclei are now called,
approach each other in order to coalesce and form a single
" segmentation nucleus." This segmentation nucleus, being
formed by the union of male and female nucleus, therefore
now contains the hereditary substance of both germ-cells,
maternal as well as paternal, and once more possesses four
chromosomes—two from the father and two from the
mother. What has been formed is, indeed, the mother-
cell, from which the new individual arises in the ordinary
manner of cell-division—that is, the chromosomes split
lengthwise, wander to the opposite poles, and surrounding,
themselves with the separated halves of the cell-body, form
two new daughter-cells, each possessing, again, four chromo-
somes—namely, two from the father and two from the
mother. The daughter-cells repeat this process of division,
and by continued subdivision of the same kind the organism
is finally built up. Thus is brought about the mingling of
the parental qualities in the mother-cell and their equal
distribution throughout the line of the descendant body-
cells.

It may seem from the description of these facts as if
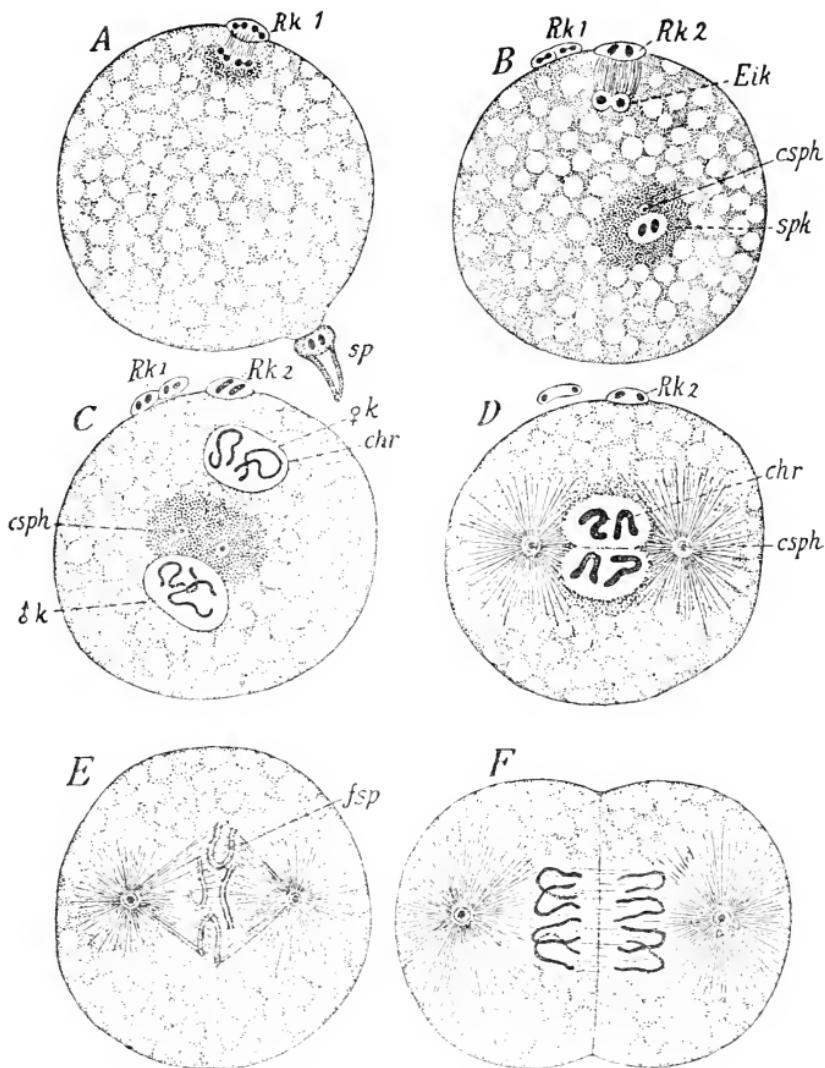
FIG. 31.—FERTILIZATION IN ASCARIS MEGALOCEPHALA. (Adapted from Boveri and Van Beneden.)

(From Weismann, " The Evolution Theory.")

A, spermatozoon (*sp*) about to penetrate ovum which has one polar body (*Rk* 1); *B*, spermatozoon (*spk*) with its centrosome (*csph*) has entered ovum, which shows ovum-nucleus (*Eik*) and three polar bodies (*Rk* 1 and *Rk* 2); *C*, sperm-nucleus (♂ *k*) and ovum-nucleus (♀ *k*) show each two chromosomes; *D*, coalescence of sperm- and ovum-nucleus into segmentation nucleus; *E*, division of segmentation nucleus; *F*, formation of the first two embryonic daughter-cells.

in the act of fertilization the combination of both elements, male and female, were an essential, both being, as it were, complementary to each other. But this is by no means the case. Male and female nuclei are not two different halves producing together the new offspring, but both are equal, each representing by itself a complete individual. This will at once become apparent from the fact that for the purpose of embryogenesis (development of the embryo) either of the germ-nuclei may in certain circumstances be dispensed with.

Thus Professor Delage has shown that non-nucleated fragments of eggs of the sea-urchin (*Echinus*) can be successfully fertilized by the sperm and develop into an embryo, showing thereby that the presence of the ovum nucleus is not a condition *sine quâ non* of embryonic development. On the other hand, that the sperm-nucleus can be dispensed with appears from some experiments of Professor Loeb. He induced ova of the sea-urchin *Arbacia* to develop parthenogenetically—*i.e.*, without the intro-duction of a spermatozoon — by bringing them for a short time into a mixture of 50 per cent. sea-water and 50 per cent. magnesium chloride.

The cases of partial and total Parthenogenesis already mentioned also point to the same conclusion—that the egg-cell alone is capable of starting its own embryogenesis.

We have thus in fertilization a twofold process : firstly, a stimulus given to the germ-cell towards embryogenesis, this stimulus being supplied either by the germ-cell of the opposite sex or by some other means ; and, secondly, amphimixis—*i.e.*, the co-mingling of the hereditary sub-stances of the two parent-nuclei.

V.—DEVELOPMENT.

In accordance with their theories of fertilization, the Ovists and Animalculists held that the future embryo was contained in the ovum or spermatozoon respectively. They
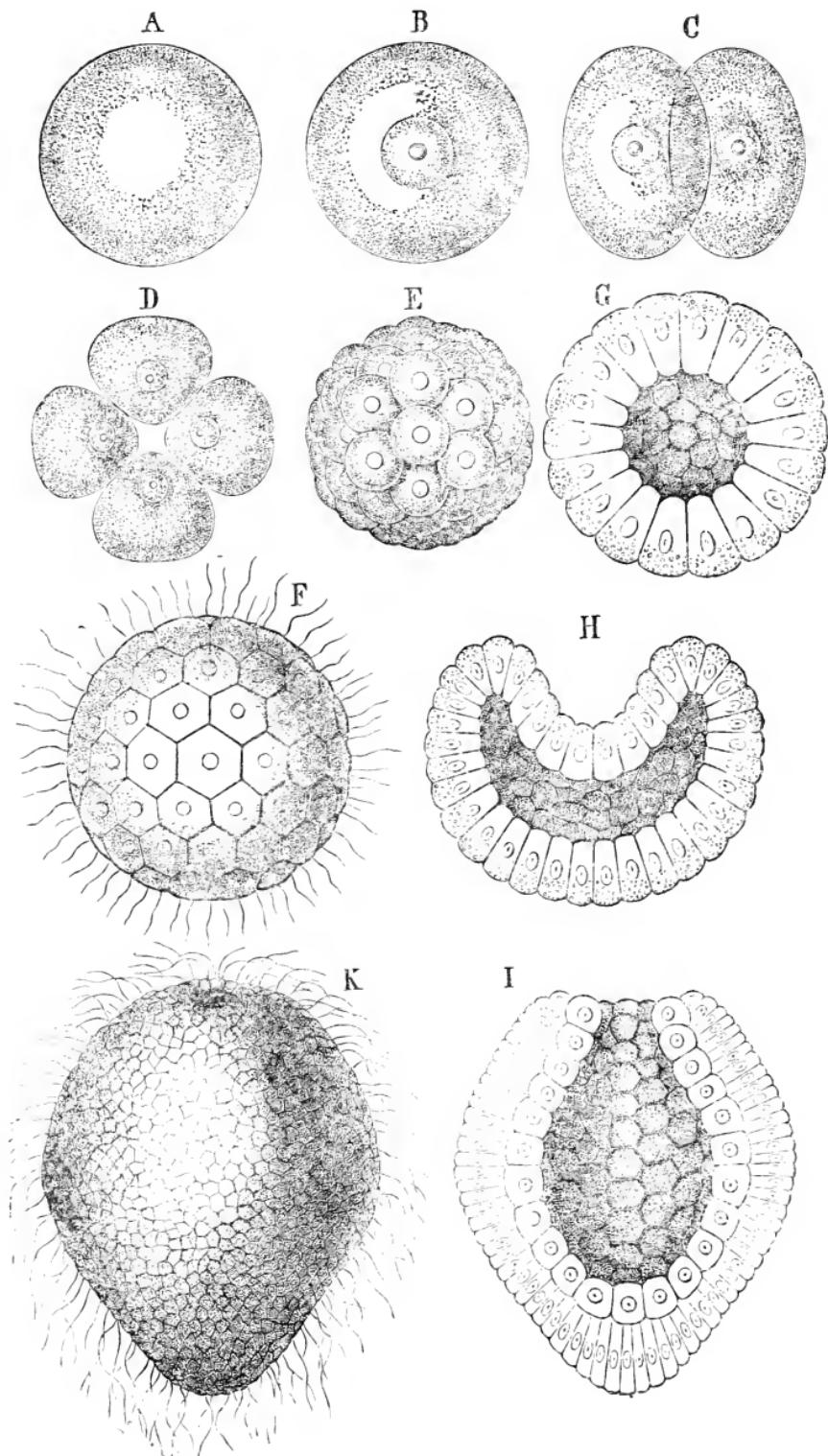
FIG. 32.

conceived the embryo lying literally ready made in the
germ-cell they respectively favoured, though in a very
minute form. All that was supposed to take place was
an unfolding of the preformed embryo (*evolutio*), as a bud
unfolds itself into a flower. This theory is known, there-
fore, by the name of Preformation or Evolution theory
(Evolution not to be confused with Evolution in the
modern and wider sense of progressive development),
also Scatulation theory, because the miniatures of the
successive generations were imagined to lie, like nests of
boxes, one within the other, in ever-increasing minute-
ness.

It is evident from what has been learnt already that this
crude theory is altogether baseless and unsubstantiated

Fig. 32.—Gastrulation of a Coral (Monoxemia Darwinii).

(*From E. Haeckel, " Evolution of Man."*)

A and *B*, impregnated ovum (in *A* immediately after fertilization
the nucleus is invisible); *C*, two segmentation cells; *D*, four
segmentation cells; *E*, morula; *F*, blastula; *G*, transverse section
of *F*; *H*, hollowed blastula (transverse section); *K*, gastrula;
I, longitudinal section of *K*.

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by facts. The truth had, indeed, been vaguely guessed
at here and there (Aristotle, Harvey), but was only
finally established by the splendid observations of Caspar
Friedrich Wolff, who in his *Theoria Generationis* (*Theory of
Generation*) (1759), demonstrated conclusively that the
chick gradually assumed its complex organization from a
comparatively simple and homogeneous matrix. The
organs were not preformed, " but could actually be seen
being formed." Later Von Baer first formulated the funda-
mental laws of this development by showing how the
embryonic cells arranged themselves first into the germinal
layers, then into the different tissues, organs, etc.

Just to indicate in outline the first stages of embryo-
genesis, we must remember that we distinguished, according

to the arrangement of the yolk, four kinds of ova. We
had the ovum with (1) diffuse, (2) central, (3) polar, and
(4) predominant yolk. All the different ova develop on
the same principle, which is only modified according to
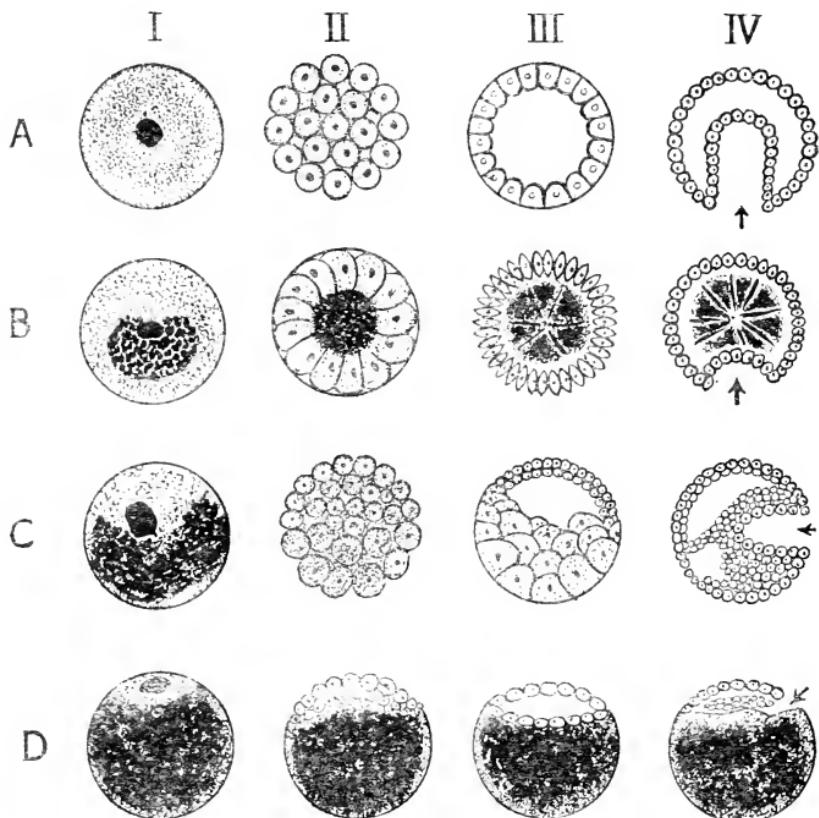
FIG. 33.—EMBRYOGENESIS OF (*A*) SPONGE, (*B*) CRAYFISH, (*C*) FROG,
(*D*) BIRD. (After Thomson and Haeckel.)

I, ovum ; II, morula ; III, blastula ; IV, gastrula.

the disposition of the yolk. First of all, we have a cell-
cleavage, the original mother-cell forming by repeated
divisions a globular mass of cells, the " morula " stage ;
then follows the formation of a cavity within this ball of
cells, the " blastula " stage ; thirdly, the " gastrula " stage

is formed by the doubling-in of the blastula, thus leading to the formation of the two primitive germinal layers, the outer, or ectoderm, and the inner, or entoderm, both enclosing the primitive mouth-cavity.   Finally, the third layer, the mesoderm, is formed between ectoderm and entoderm, and the formation of tissues, organs, etc., goes on apace until the final form of the completed embryo is reached.

We can distinguish, according to the four kinds of ova, four kinds of segmentations, with four kinds of gastrulæ, namely :

1. The egg with diffuse yolk shows equal segmentation (all the cells dividing evenly) and a bell-shaped gastrula. Types : Sponge, Amphioxus.

2. The egg with central yolk, the outer portion only dividing, has superficial segmentation, and a spherical gastrula. Types : Crusters, Insects.

3. The egg with polar yolk has unequal segmentation, the cells at the upper pole, free from yolk, dividing faster and leading to a hooded gastrula.   Types : Amphibians.

4. The ovum with predominant yolk, where again only the germinal vesicle divides on top of the yolk, thus leading to the discoid gastrula. Types: Reptiles, Birds, Monotremata.

There is only one more point to which we wish draw attention in this connection.   As the mammals have descended genetically from the reptiles and birds, yet have lost the yolk of their eggs (the mammalian embryo is nourished within the uterus of the mother, and does not need the yolk), the development of the mammalian ovum has reverted from the bird-type, which is still prevalent among the Monotremata, the lowest mammals, to a more primitive type, though the exact details are not yet completely cleared up.   On the other hand, the lowest vertebral animal, the Lancelet or Amphioxus, has a segmentation of the most primitive type, like the sponge, showing thus the close connection between the two species so far distant in the scale of organization.

CHAPTER IV

THEORIES OF HEREDITY

WHILE the last chapter gave us a survey of the " facts of heredity," showing us in brief outline the chief phenomena connected with the reproductive process, we now come to the theories of heredity—that is, those ideal systems which have been thought out in order to interpret and explain these facts. Just as the atomic theory was formulated with the object of explaining the chemical constitution of matter, so a theory of heredity is intended to serve as a working idea of the fundamental problems of the living organism. But there is this one great drawback— that, while the atomic theory has been universally accepted as valid, we are still face to face with a multitude of contested theories of heredity.

We purpose here to treat only the most important of these theories, and these only in so far as they variously show special bearing on the subjects we have under discussion. Following the same order as that previously adopted, we may conveniently deal with these subjects under the heads of Reproduction (including Regeneration), Maturation, Fertilization, and Development.

I.—THEORIES OF REPRODUCTION (including REGENERATION).

We have seen that reproduction takes place either by simple division of the whole organism into two, or by means of greater or lesser parts of the individual, which, finally constituting themselves as special cells, form the germ-cells.

While there seems to be nothing wonderful in the fact that the two daughter-cells of a divided mother-organism should display the same nature and constitution as the original mother-cell, one of the most puzzling problems of biology has been : Why does the germ-cell reproduce the parent ?

It is this which is the central question involved in the problem of heredity, and to which, as we shall see presently, various answers have been given.

Omitting altogether the old metaphysical attempts at a solution, we may choose as representatives of the modern scientific ideas the four following :

    (a) Herbert Spencer's theory of physiological units.
    (b) Charles Darwin's theory of Pangenesis.
    (c) Francis Galton's Stirp theory.
    (d) Weismann's Germ-plasm theory.

We shall be able to trace a certain historical and logical sequence in these theories, which will become apparent on closer examination of them.

(a) SPENCER'S PHYSIOLOGICAL UNITS.

To Spencer belongs the honour of having conceived the fruitful idea of organic units, by means of which he was enabled in his *Principles of Biology* (1864) to put forward the first thoroughgoing scientific theory of heredity. Starting from the fact that regeneration is a common occurrence among living organisms, he tried to explain the reparation of lost tissues or organs by the assumption that the remaining units of the body have a natural tendency to arrange themselves into the shape and form of the missing part. Further, taking the Begonia leaf, which is capable of growing a new plant from the tiniest fragment, he instances this as likewise leading to the same idea—that " the active units composing a plant or animal of any species have an intrinsic aptitude to aggregate into the form of that species." The units composing the whole

body could, according to him, neither be inorganic chemical molecules, as not having the properties of life, nor, on the other hand, morphological, *i.e.*, cellular, because the cells themselves are already organized ; but these units could only lie between both, and were therefore called by Spencer " physiological " or " constitutional " units. Further, just as a crystal in a suitable medium will complete itself and crystallize in its proper form, so the physiological units possess " organic polarity "—that is, they have, as already mentioned, the power of arranging themselves into the shape of the body to which they belong. The units are different for each species, and also vary slightly according to the peculiarities of each individual, but all the units of each body are alike (in this respect Spencer's theory differs fundamentally from the three others to be discussed), and the formation of the different tissues, organs, etc., is solely due to the different arrangement of the units according to the influence and local condition of neighbouring units. " The germ-cells are," to quote Spencer's own words, " essentially nothing more than vehicles, in which are contained small groups of the physiological units in a fit state for obeying their proclivity towards the structural arrangement of the species they belong to. . . .   There is no warrant for the assumption that they possess powers fundamentally unlike those of other cells.   The inference to which the facts point is that they differ from the rest mainly in not having undergone functional adaptations." Spencer imagined, we see, the germ-cells as an assembly of physiological units derived from the body, and ready to start the new individual under appropriate conditions. He further maintained, and tried to prove from " first principles," that any force acting on the totality of the body, and modifying its units, must necessarily react on and remould all the units of the body in harmony with this new influence, not excepting those physiological units which, " when separated from the body in the shape of repro-ductive centres," build themselves up into the new indi-

vidual. According to this theory, therefore, the germ-cells, and with them the new progeny arising out of them, are permanently modified by environmental forces acting on the parent-body, or, in other words, characters acquired by the parents are, as a matter of course, inherited by the offspring.

For this purpose Spencer had to assume, as we shall find Darwin similarly did, that the physiological units circulate through the body, and " that in course of time all of them visit all parts of the organism."

Great as is the conception of physiological units by Spencer—having served as the starting-point for nearly every modern theory of heredity—there are three out-standing criticisms which have to be made against this theory : Firstly, the simple quality of organic polarity of his units is not sufficient to explain the manifold formations of the organic body, least of all the wonderful changes during the progressive stages of embryogenesis. Indeed, to say that the units have a natural proclivity towards the formation of the body amounts hardly to much more than a verbal explanation. Secondly, the theory assumes the germ-cells to be nothing more than small groups of physio-logical units, being, as it were, an offshoot of the body. As will be shown later, this is not consistent with the now generally accepted idea of the relationship between body-and germ-cells. Spencer asserts that the germ-cells are in no essential different from any other body-cell, holding that every body-cell would, under ideal conditions, be capable of reproducing the whole body (refer to Begonia leaf) : a generalization hardly supported by facts. And, lastly, Spencer tries to deduce from the general principles of force that modifications wrought on the parent-body must necessarily produce the same modification in the offspring, an inference which cannot legitimately be made for biological phenomena, leading, as it does, to the un-warranted, experimentally disproved assumption that the physiological units actually circulate through the body.

(b) Darwin's Pangenesis.

The theory next in time and importance is the theory of Pangenesis, put forward by Charles Darwin as a provisional hypothesis in his *Variation of Animals and Plants under Domestication* (1868).   He assumed that each cell of the body during all its stages of development throws off minute particles, the " gemmules," which are characteristic of each such cell during its respective stages, and are able to multiply and reproduce the cell with its qualities at the propitious moment.   The gemmules circulate through the body, and accumulate at particular places of it—that is, at those which give rise to buds, etc., but especially in the sex-elements of the organism—which thus contain representative gemmules from each unit of the body during all its stages.   In this way it is explainable why the germ-cells are able to reproduce the parent with all its characteristics.   During Ontogenesis (the development of the individual) each embryonic cell, as it divides, is entered by the gemmules which represent the cells of the next stage of development, and which by a sort of fertilization, as it were, induce this cell to assume the structure of the body-cell they represent.   In the same way it must be assumed that in the regeneration of lost parts, etc., the right kind of gemmules is attracted by the cells which divide to repair the loss.   Some of the gemmules during the development of the sex-cells may remain latent for one or more generations.   Thus, the sexual character of a grandfather (beard, etc.) may be transmitted through his daughter to a grandson ; or, in cases of Atavism or Reversion, traits of far-back forefathers may reappear, showing that the gemmules representing those characters were dormant, and became active once more in the individual which shows the trait anew.   Lastly, Darwin assumed that cells modified by changed conditions of life will throw off modified gemmules, such gemmules, of course, reproducing parts modified in the same direction.

We see that in this last hypothesis—the inheritance of acquired characters—Darwin is at one with Spencer. Both theories further agree in looking upon the germ-cells as aggregations of particles derived from the body, both necessarily assuming with this a circulation of these particles through the body, and their migration towards special points of the body, be they germ-cells or future budding parts of it.

In so far, the criticisms against Spencer's theory will hold good also against Darwin. There is, however, a fundamental distinction between them. Spencer assumed his physiological units to be all alike, their arrangement alone leading to differentiation of organs, etc. : Darwin's gemmules, on the contrary, vary according to the special cells they represent ; they can reproduce only those cells from which they are derived.

Valuable as the idea of specific representative particles has proved to be for the study of heredity, it is, as propounded by Darwin, hardly more than a formal solution of the problem. As Weismann has put it : " If we suppose that each cell arises from a special gemmule, and that these gemmules are present whenever they are wanted, it is easy to see how that structure, the origin of which we wish to explain, may appear in any given position." Furthermore, to assume that the cells are all identical before they attract the gemmules which give them their individuality, and yet at the same time to invest these cells with the most delicate selective power for the various gemmules they attract, is, as Yves Delage has shown, not to solve the question, but to put it anew.

(c) GALTON'S STIRP THEORY.

The main objection against all pangenetic theories is the assumption which has to be made, that the units or gemmules, or whatever their name may be, circulate freely through the body, to accumulate finally in the sex-cells.

Not only is this biologically inconceivable, but it has been definitely disproved by Galton by experiments expressly made for that purpose. To obviate this difficulty, therefore, Galton himself propounded a new theory of heredity in 1875, which, with its insistence on the distinction between body-cells and germ-cells, may be taken as a type of all successive theories of germinal continuity.

Galton uses the word " stirp " (*stirpes*, Latin =root) " to express the sum total of germs (gemmules), or whatever they may be called, which are to be found in the newly-fertilized ovum " (or in a budding-point of an organism). " The stirp contains a host of germs, much greater in number and variety than the organic units of the structure that is about to be derived from them, so that comparatively few germs achieve development." Further, " the germs that are not developed retain their vitality ; they propagate themselves while still in a latent state, and they contribute to form the stirp of the offspring."

We have therefore, according to Galton, the stirp divided into two parts, the " dominant " germs developing into the body of the individual and the " residual " germs which form the sex-cells of that individual, and, propagating themselves, give rise to the next progeny. There is thus direct descent between stirp and stirp, and not, as hitherto assumed, between body and body. Indeed, Galton's theory was devised mainly to account for the genetic relationship between successive generations. Only as an act of grace, as it were, did he assent to a very limited possibility of the transmission of acquired characters. For that purpose he admitted Darwin's explanation that, exceptionally, a few germs may be thrown off by the body-cells, which, finding their way into the germ-cells, are incorporated with them.

(d) WEISMANN'S GERM-PLASM.

We now come to the last of the theories of heredity mentioned above—namely, the one propounded by Weismann. The fundamental distinction between that part of the germ which builds up the body and that which remains as the germ-cells to constitute the next generation is retained and further worked out. But Weismann also tried to solve the problem of the orderly arrangement of the units, which are the bearers of the hereditary qualities, by a profound, though rather complex, hypothesis.

Weismann elaborated his system only gradually in a series of essays (published together under the title *Essays on Heredity and Kindred Subjects*), but gave a complete statement of his final views in his book, *The Germ-Plasm*, in 1893, and once more in abbreviated form in his *Evolution Theory* in 1904.

Weismann distinguishes, with Naegeli, two kinds of substances in the body—the " morphoplasm " (what Naegeli had called the " trophoplasm "), which is the living protoplasm of the cell-body, and the " idioplasm," which is the bearer of the hereditary qualities of the organism and the active formative element of it. But while the latter, according to Naegeli, was distributed throughout the cell-bodies of the organism, Weismann, with the newer knowledge, relegated the idioplasm to the nuclear structure of the cells.

Weismann's units are the " Determinants "—thus called because they determine the nature and quality of the cells and parts of the body which they represent. They have, like all living units, the power of growing and multiplying by simple division. There are as many determinants as there are independently variable parts of the body, be they single cells, groups of cells, or even portions of cells, so long as any such part is capable of varying independently from any other. For as each part of the organism has its own character, on the strength of the determinant which im-

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presses it, if two parts had only one determinant, any change of this determinant would alter both parts simultaneously. The very fact that both parts can change independently from each other leads to the conclusion that they must each be represented by a separate determinant. Thus, for instance, we could imagine the whole skin represented by one determinant only; but as a minute portion of the skin may vary in its character (*e.g.*, a wart may exist on one side of the face), we must imagine that portion of the skin bearing the wart represented in the germ by a separate determinant; and as all parts of the skin may thus vary, each of them must have a separate determinant. In the same way the minute coloured scales on the wings of butterflies, or the different patterns of feathers in birds, are each and all extremely variable, and must therefore be determined by separate units. It is otherwise, on the other hand, with the red blood-corpuscles; these do not seem to vary from each other, and may therefore be represented by a single determinant.

All the determinants necessary for the development of the organism are gathered together in a higher unit, which is called the " Id," also with the power of growth and self-propagation. These Ids are identical with the " microsomes " or " chromomeres," the small globular bodies of which the chromosomes can sometimes be seen to consist. There must therefore be a still higher unit than the Id, the Chromosome, or, as Weismann has called it, in conformity with his nomenclature, the " Idant." We see, therefore, that each germ-cell having many Idants (chromosomes), each consisting of a number of Ids, contains the representative units of many individuals; each single Id, with its determinants, standing for a complete individual.

The idioplasm which is contained in the germ-cell has been specially named by Weismann the " germ-plasm." It comprises, as has been seen, the constituents for the construction of the new being. Weismann holds it as an uncontroverted fact that the body-cells cannot, as, for

instance, Darwin still held, reproduce the germ-cells.
Once the body-cells of the new organism are formed, they
are specialized and incapable of assuming the function of
germ-cells, simply because, as we shall see presently, they
do not any longer contain all the determinants necessary
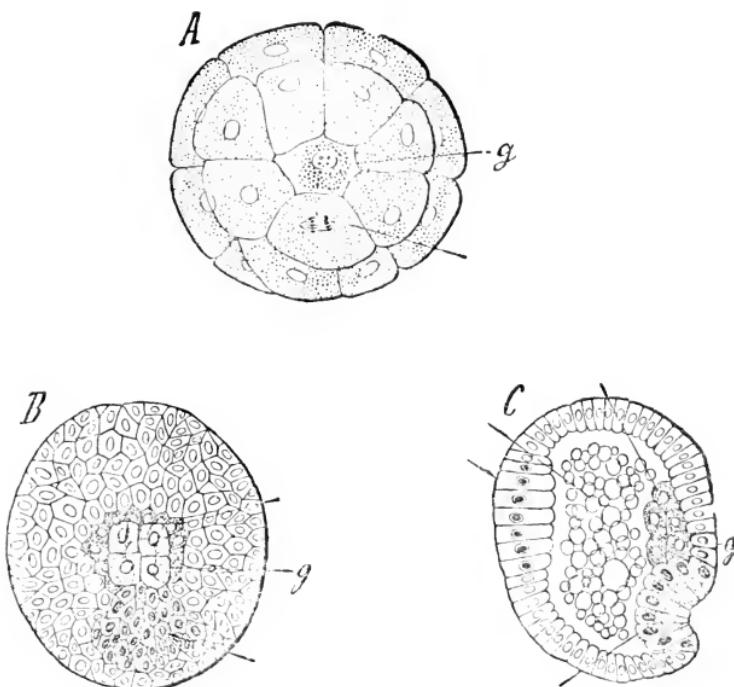
FIG. 34.—SUMMER EGGS OF MOINA.   (After Grobben.)

(*From Weismann, " The Germ-Plasm."*)

A, morula stage ; *B*, blastula stage ; *C*, gastrula stage ; *g*, primitive
germ-cells.

for the upbuilding of an organism.   The body, therefore,
being incapable of producing the germ-cells anew, there
remains the only other possibility of deriving the germ-
cells for the production of the next generation directly
from the germ-cells of the parents.

Indeed, in some, though rare, cases such direct relation-

ship between germ and germ can clearly be traced. Thus, among the *Diptera* the first segmentation divides the ripe ovum into two cells, of which one is the mother-cell of the future body, while the other is the mother-cell of the germ-cells of the new individual to be formed. In the embryogenesis of the water-fleas (*Daphnides*) the primitive germ-cells are separated from the body-cells (" somatic " cells) during the early stages of segmentation, while in the *Sagitta*-worm this differentiation of the germ-cells takes place somewhat later still during the gastrula stage. In these latter cases the germ-plasm of the next generation is
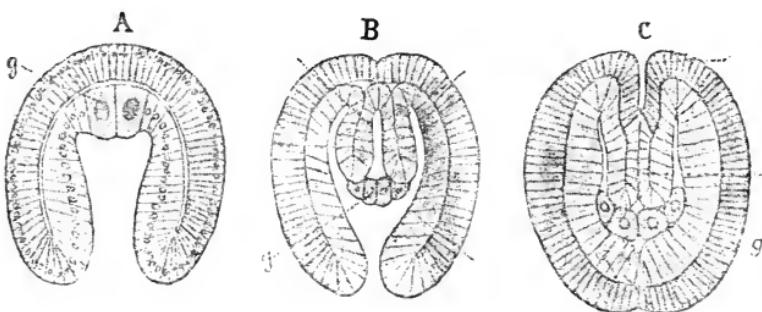
FIG. 35.—DEVELOPMENT OF SAGITTA.   (After Hertwig.)
(*From Weismann, " The Germ-Plasm."*)
A, *B*, *C*, three successive stages ; *g*, germ-cells.

therefore not immediately separated from the other idioplasm of the body, but is carried along in a latent state in some of the primitive body-cells, during a few of their earlier stages, until it is separated in the form of distinct germ-cells. Now, this differentiation of the germ-cells may be put off until very late in the development of the body structure, the germ-plasm being handed down in a latent, inactive state from cell to cell, without in any way influencing at any stage the body-cell in which it happens to be contained. The route which the germ-plasm follows—*i.e.*, the succession of cells through which it passes until it finally splits off in the form of distinct germ-cells—

is always the same for any given species, and has been called by Weismann the " germ-track." Fig. 36 will make this clear. We have, then, if not a continuity of germ-cells, as in the first-mentioned cases, a " continuity of the germ-
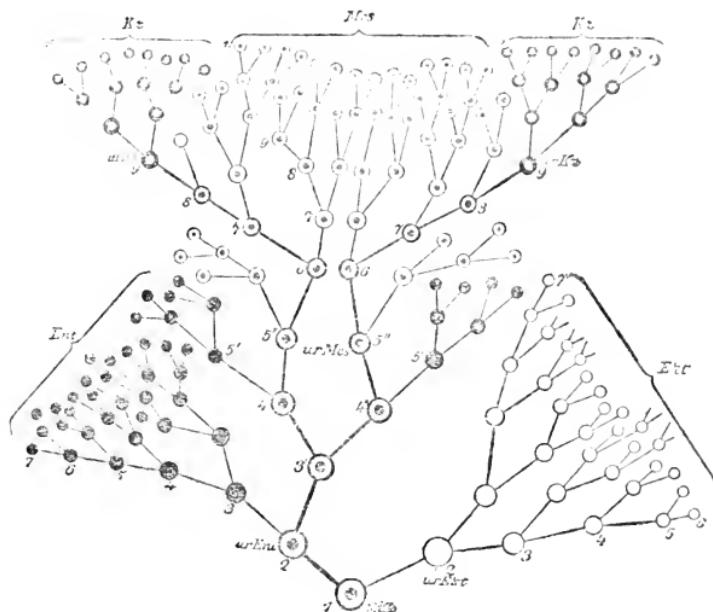
FIG. 36.—DIAGRAM OF GERM-TRACK OF RHABDITIS NIGROVENOSA.

(*From Weismann, " The Germ-Plasm."*)

The primitive mother-cell (*Eiz*) divides into the primitive ectoderm cell (*urEkt*) and the primitive entoderm cell (*urEnt*), the former forming the cells of the ectoderm (*Ekt*, white), and the latter those of the entoderm (*Ent*, black). The primitive entoderm cell (*urEnt*) further forms the primitive mesoderm cells (3', 4', 5", *urMes*), which in their turn give rise firstly to the mesoderm (*Mes*, rings with dots), and secondly to the primitive germ-cells (*urKz9*), from which arise finally the germ-cells (*Kz*, black rings).

plasm." Contrary to the commonly-held opinion that the body creates the germ-cells, the body must, according to Weismann, be considered a product of the germ. It may conveniently be pictured (see the accompanying diagram

Fig. 37) as an outgrowth of the germ-cells, which, with
the progressive evolution of species, has become ever
larger and more complex.

The germ-plasm, with its Determinants, Ids and Idants,
has, according to Weismann, a definite architectural
arrangement, which in some way is representative of the
body, but is by no means identical with it. (This latter
notion would involve a revival of the old crude idea of
preformation, which considered the germ to contain a
complete individual in miniature.) The order of the
ontogenetic stages* of the embryogenesis is due to the
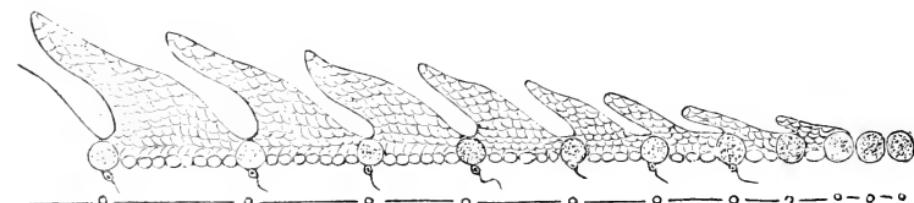
FIG. 37.—THE RELATION BETWEEN THE REPRODUCTIVE CELLS AND
THE BODY.

(*From Geddes and Thomson, " The Evolution of Sex."*)

The continuous chain of dotted cells at first represents a succession
of protozoa; further on it represents ova, from which the
" bodies " are produced. At each generation a spermatozoon
fertilizing the liberated ovum is also indicated.

inherent forces in this structural arrangement of the germ-
plasm. As the body passes through its different phases
of development by the fission of the primitive cells, the
right determinants multiply and come into activity, sever
themselves from their group-connections, and determine
the character of each cell as it appears. The remainder of
the determinants for all the later cell-sequences are
carried forward in a latent state, until one determinant
after the other falls out of the complex group of deter-
minants to determine its own cell, so that finally only one

* Ontogenetic stage = each single stage of the embryonic develop-
ment.

kind of determinant is left for the final cells of the body. Only one kind of determinant is destined for each kind of cell, be this cell temporary or permanent. The influence of the determinants on the cell-body is due to their final disintegration into the " Biophors," the smallest living particles of which they are composed. These, which are characteristic for each kind of determinants, leave the nucleus, enter the cell-body, and impress on the morphoplasm of the cell the appropriate character.

Just as the formation of the normal cells, organs, etc., of the body is due to the presence of a special kind of determinant, so does Regeneration, according to Weismann's view, also depend on the right kind of determinants being present at the place of regeneration. These determinants must exist as " adventitious germ-plasm " in a latent state, wherever regeneration is possible, until occasion arises for them to become active. In such cases, as in a divided worm, where both ends may regrow the missing portions of the body, it is, of course, necessary to assume that at the plane of partition two sets of determinants are present, those for the fore-parts and those for the hind-parts of the body, and that each kind becomes active, according to which part of the animal has to be regenerated.

Many fundamental objections have been raised against Weismann's system of determinants, which it would be impossible to deal with here. Professor Delage, a French scientist, goes perhaps farthest in denying the necessity of any kinds of units. He thinks he can explain all the various phenomena of heredity, etc., by the interaction of forces between the physico-chemical constitution of the living germ and external conditions, just as we get by the reaction between water and different physical forces its various forms of rain, snow, hail, river, etc.

Oscar Hertwig, who does not accept determinants for any other characters of the body than actual cell-qualities, attributes characters determined by groups of cells (as

hair, feathers, stripes, etc.) to the interaction and co-operation of various cells.   He admits some kind of organization for the germ-plasm ; though, as we shall see later, he lays considerable stress on the accompanying influences between the cells themselves—*i.e.*, forces external to, and not originally residing in, the germ-plasm.

The greatest objection against Weismann's teaching that the formation of any part of an organism can be due only to the presence of active specific determinants seems to be furnished by those pathological cases where, after the fracture of a bone, a false joint is formed, with proper capsule, etc.   Here we have only two alternatives : either adventitious determinants are present in a latent state wherever the formation of a false joint may happen to occur—a very unlikely provision for pathological cases— or a specific structure can be formed without such determinants.

We are, as can be seen, in the not very fortunate position, pointed out at the beginning of the chapter, that not one of the theories propounded is free from objections and contradictions.   Not a single theory can be made to fit in with *all* known facts.   On the whole, Weismann's theory seems to give the most complete explanation, an explanation to which in its fundamentals we must hold ourselves, with more or less modifications, in the present state of our knowledge.

In the following paragraphs of this chapter and the next we shall therefore mainly follow Weismann's detailed statements, as at least offering a working model for picturing to ourselves the intricate processes of inheritance.   Of other theories we shall mention only as much as appears essential for the discussion.

II.—THEORY OF MATURATION.

We have seen that the germ-cells possess before maturation the ordinary number of chromosomes typical of the cells of the species, but that they lose in the process of

maturation half the number of chromosomes. What is the reason for this reduction of chromosomes? It is evident that, as soon as reproduction takes place by the union of two sex-cells, each of which contains the full

Father.　　Mother.　　Offspring.

I. Generation.

II. Generation.

III. Generation.

IV. Generation.
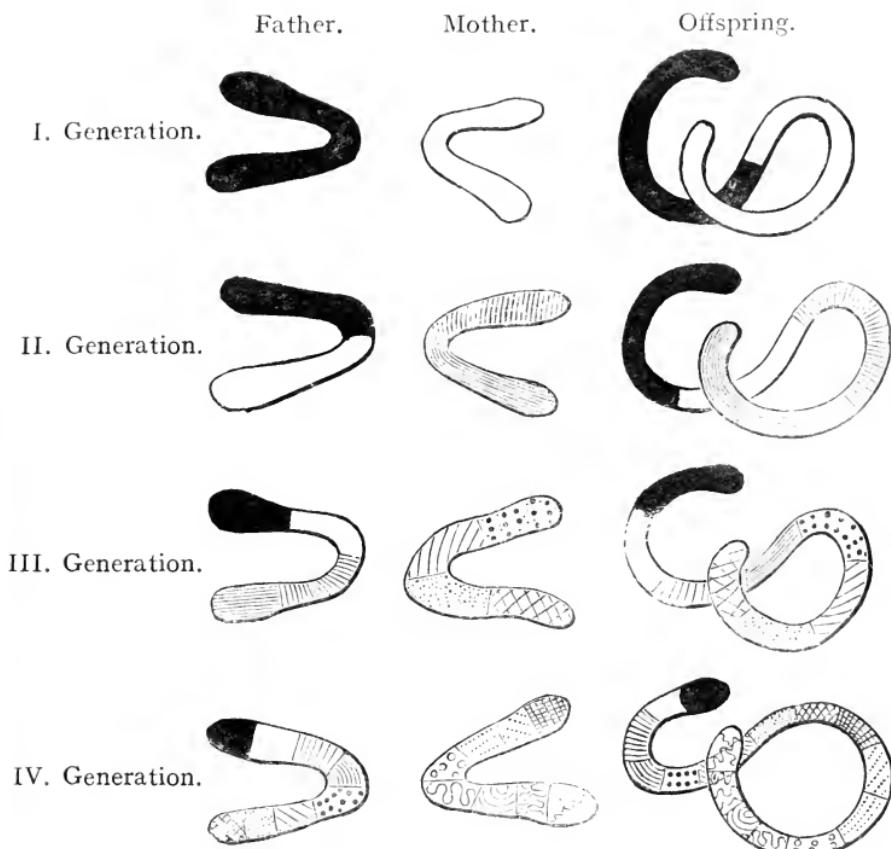
FIG. 38.—COMBINATION OF IDANTS.
(*From Weismann, " The Germ-Plasm."*)

number of chromosomes, the resulting mother-cell would have double the number of chromosomes. If this process went on for any length of time the number of chromosomes would multiply enormously, and soon not be able to find room within the nucleus. The reducing division then has

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the effect of removing each time half the number of chromo-
somes from the germ-cell, so that by the union of two germ-
cells in the act of fertilization the original normal number
is once more restored.

The reducing division has the further effect of changing
the composition of the germ-plasm of each germ-cell. If we
assume that before the introduction of Amphimixis among
organisms (see Fig. 38) the germ-plasm of the male germ-
cell had 16 Idants (16A), all equal, we should get, after the
reducing division, 8A, and if these combine with 8B from
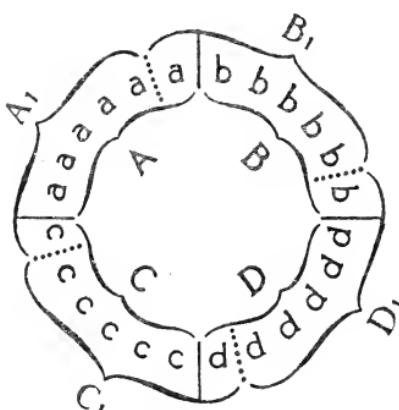
FIG. 39.—CHANGE OF IDS.
(After Delage.)

a female germ-cell, we get a
germ-plasm, 8A + 8B. Now,
a further reducing division
takes place in the next
generation, and leaves for the
germ-cell again half the num-
ber—*i.e.*, 4A + 4B. These,
combined with 4C + 4D from
the mother, give us a germ-
plasm of the composition
4A + 4B + 4C + 4D. If we re-
duce again by half, and so
on, we obtain ultimately a
germ-plasm consisting of 16
different Idants, A, B, C,

D, E, F, etc., though in reality this reducing division may
not have taken place so regularly.

But this process goes farther still. Not only all the
Idants become individually different, but also their Ids.

We have already pointed out in a previous chapter that
the reducing division differs from the ordinary cell-division
in that it divides the chromatin into two qualitatively
different parts. We must now add that this division does
not necessarily fall between the individual chromosomes
or Idants. If we have (see Fig. 39) 4 Idants, A, B, C, D,
each with 6 identical Ids—*i.e.*, Idant A with 6 Ids *a* ;
B with 6 Ids *b* ; C with 6 Ids *c* ; and D with 6 Ids *d*—then,

if we assume them represented diagrammatically in a circle, the division does not necessarily separate each time 2 Idants with identical Ids, but may fall near the point of junction of the Idants, and divide the Idants in such wise that the new Idants A^1, B^1, C^1, and D^1, each have 5 Ids of one kind and 1 of another kind—*i.e.*, $A^1 = 5a + 1c$, $B^1 = 5b + 1a$, $C^1 = 5c + 1d$, and $D^1 = 5d + 1b$. If the same now happens to the new Idants of the next generation, and so on during many generations, we shall finally get Idants containing Ids all of a different character. As each Id represents a complete individual, we have therefore in the germ-plasm represented many individuals of different tendencies and characters.

Furthermore, the reducing division, by removing each time one set of chromosomes from the germ-cells, leaves them with a variety of different chromosomes, so that we get from each individual a variety of germ-cells, each expressing different hereditary tendencies and characters. Thus, let us assume we have a germ with four chromosomes, ABCD. As each time during the reducing division a set of two chromosomes is removed, we have the possibility of six different germ-cells, containing two chromosomes each—viz. :

> AB, BC, CD.
> AC, BD.
> AD.

Each of these, of course, expresses different hereditary traits. But we further know that before the reducing division a doubling of the chromosomes takes place. This, according to Weismann, has the purpose of still further increasing the variety of germ-cells.

If we take again a germ with four chromosomes, ABCD, and we double these, we get

> ABCD
> ABCD.

Now, from these we can derive ten different kinds of germ-cells, each containing two chromosomes—viz :

> As before : AB, BC, CD.
>   AC, BD.
>   AD.
>
> Further : AA.
>   BB.
>   CC.
>   DD.

We have now ten different kinds of germ-cells, instead of six, from the same parent.

Now, in fertilization each such germ-cell unites with another one. We get, therefore, in the former case the possibility of $6 \times 6 = 36$ different kinds of offspring, and in the latter case $10 \times 10 = 100$ different kinds of offspring. This number rapidly rises with the number of chromosomes :

Without Doubling.			With Doubling.
Chromosomes.	Germs.		Germs.
8	70	. .	266
12	924	. .	8,074
16	12,870	. .	258,670
20	184,756	. .	8,533,660

The numbers of possible different offspring are, of course, 70×70, 266×266, etc. We get, therefore, practically an infinite variety of offspring, which accounts for the fact that no two individuals in the world are found to be alike.

III.—THEORY OF FERTILIZATION.

What is the meaning of fertilization ? Why are there two sexes, the union of which is necessary for the propagation of all the higher species ?

The question has been variously answered, and it cannot be said that anything like a satisfactory solution has yet

been found. Weismann says amphimixis serves as a means for the co-mingling of two separate hereditary tendencies, and is, therefore, a source of variation. O. Hertwig and others, on the contrary, have maintained the opposite view, holding that its effect is to prevent variation. Delage thinks there is something to be said for both sides. As in the act of fertilization two ancestral strains are mixed, it is evident that this makes it possible for the child to resemble two lines of ancestors instead of one. On the other hand, any odd individual peculiarities are likely to be swamped by the addition of another germ-plasm which does not contain them, as will be seen presently.

A Mixing of Parental Qualities.

We have already seen that the germ-cells of the same parent are not all identical, but become, by means of the reducing division, individually different from each other. We know, further, that in the process of fertilization two such germs unite to form the new individual, which thus has a double inheritance—paternal and maternal. How does this double set of qualities, derived from the two parents, behave in its *ensemble*, or, in other words, in what way is the constitution of the offspring determined by the mixing of the constituent qualities of the parents ? According to the rôle and predominance of either of the parental characteristics, we can distinguish three types of inheritance :

(*a*) Blended Inheritance, where the offspring in its characteristics forms an average between both parents ;

(*b*) Exclusive or Prepotent Inheritance, where the offspring follows predominantly one parent ;

(*c*) Particulate Inheritance, where the offspring follows in some details of its characteristics the one parent, in other details the other parent.

For the sake of greater clearness, we shall first deal with the inheritance of racial traits, as exemplified in the

crossing of species and varieties, and then with the individual characters, as exhibited by the offspring of parents of the same species.*

(a) *Blended Inheritance.*

We must assume with Weismann that the majority of Ids, if not all, contained in the germ-plasm of any species, consist of determinants representing *all* the racial characters of that species. They all have the tendency to determine identical or " homologous " parts of the body, and are therefore called by Weismann " homologous Ids," containing homologous determinants. As these homologous units all strive to express identical cells or cell-groups, their action will tend in the same direction, and the effect of their determining power will be the combined result of all. On the other hand, if the determinants represent different parts of the body (as will happen with determinants of widely distant species), the determinants are said to be " heterologous "; they will not combine in their action, but mutually inhibit each other's tendencies. This explains, according to Weismann's theory, why widely different species are not fertile with each other, because harmonious combination between the very heterologous determinants of such species is impossible, each set of determinants trying to impress during the development of the organism a widely different constitution on the successive organic parts.

While the homologous determinants are identical in their effect as regards the *part* of the organism which they determine, they may differ in allied species or varieties with regard to the quality they impress on that same part.

* Much of the remainder of this chapter is very complicated, but has to be given for the sake of completeness. The beginner should not despair, but may, if unable to understand it, leave it out, and reserve it for later perusal, when he has mastered the subject better.

For instance, in two related varieties of butterflies a certain
spot on the wing may be in the one variety of a brown
colour, in the other red. The determinants, though homol-
ogous in both cases, will tend to impart a different colour
to that special spot on the wing : they will be, as Weismann
has expressed it, " heterodynamous " in their action ;
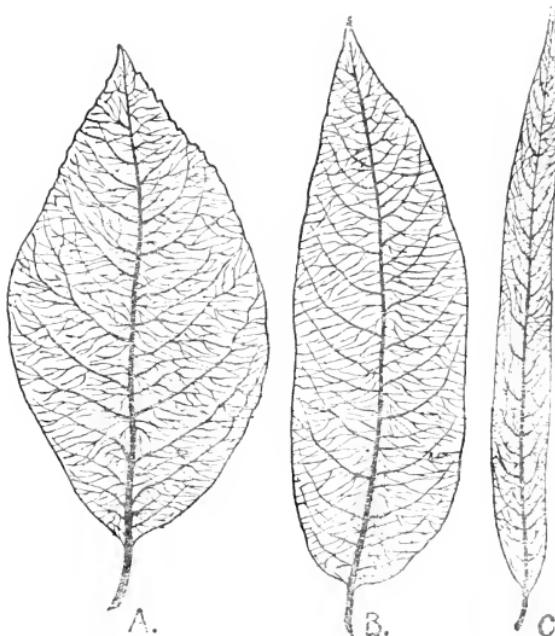
FIG. 40.—BLENDED INHERITANCE IN LEAVES OF WILLOW.

(*From J. A. Thomson, "Heredity."*)

A and *C*, the two parents ; *B*, the hybrid offspring.

while determinants impressing the same quality on any
given part of the organism would be " homodynamous "
in their effect.

Now, as the development of any cell during ontogenesis
is determined by only one kind of determinants of the
germ-plasm, and as in amphimixis homologous deter-
minants of the father and mother organism unite, it is the

combined influence of these homologous determinants which finally determines the character of any given part of the offspring.

We can now, after the above explanation, understand how it comes about that, in the crossing of two closely related varieties, the resulting hybrid shows characteristics intermediate between those of the parents. The two crossed varieties possess an equal number of determinants, which are all homologous, but heterodynamous. Both kinds of determinants will, therefore, exert the same determining power on the cells they impress, so that the result will be equal representation of both kinds of determinants or a blend of both parental qualities. A good instance of blended inheritance is presented by crossing of the white and black races of man, where the children (mulattoes) are neither white nor black, nor a mixture of white and black patches (piebald), but an intimate blend of both colours—viz., a chocolate brown.

For plants we give the accompanying illustration (Fig. 40) as an example.

(b) *Exclusive Inheritance.*

Exclusive or prepotent (preponderant or unilateral) inheritance in hybrids may be due to two causes. Firstly, one of the parents may possess a greater number of Idants and Ids, which would, therefore, become predominant in their effect over the Ids of the other parent. Or even with an equal number of Ids in both parents, the determining power of the respective biophors of each parent may be unequal, a struggle of the biophors taking place, and resulting in the overpowering expression of one set of biophors. For in the last instance, the biophors into which the determinants dissolve determine the character of the cells ; the biophors from one parent, though equal in number to the other, may be stronger, may lead to the suppression of the weaker biophors from the other parent, and thus to an apparently one-sided inheritance.

(c) *Particulate Inheritance.*

It has been indicated above that the determinants of any given species are representative of all the racial characters of that species, but we added that this is the case only for the determinants of a majority of Ids. In fact, not all the Ids contain determinants representative of *all* the characters of the species. In other words, the process described already under Maturation, showing that the Idants and Ids of the germ-plasm become individually different from each other, goes still farther, and applies to a certain extent also to the determinants. A certain change in the determinants of the Ids takes place, so that not all the Ids contain exactly the same kind of determinants. This is due to the progressive evolution of the species, by means of which the species varies, and gradually alters its characteristics in the course of time. Corresponding with the appearance of new characters in a species, the determinants of the species will be altered (indeed, the change of the determinant precedes that of the part expressed by it), the change appearing first in a few Ids, then in more, until, when a new character is firmly established, it will be represented by the determinants in most of the Ids of the germ-plasm. A minority of determinants may still exist, representative either of the past stages or of new incipient stages of the species. We have thus in the germ-plasm of any species two kinds of determinants—the majority, being homodynamous, representing characters of the species well established, and a minority of determinants, representative of characters in all stages of transition, which, therefore, in their action would be heterodynamous.

Now, the number and strength of the homodynamous and heterodynamous determinants may be different for the various parts of the organism, and may vary differently in the germ-plasm of the father and mother species. If, then, during the development of the individual each time a different set of determinants becomes predominant at a

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certain stage, we may get either paternal or maternal characters expressed, according as the paternal or maternal determinants of a certain cell-stage act homodynamously together or not. To make the case clear, we may take Weismann's illustration of a plant species A, which has an old-established form of the flower, but a newly acquired form of the leaf ; while in the crossed species B the form of the flower is new, but the form of the leaf old. There will be, therefore, in species A more homodynamous determinants for the flower than for the leaf ; while in species B there are more homodynamous determinants for the leaf than for the flower. The hybrid of both will, therefore, have a great tendency to have the form of the flower from A, but that of the leaf from B.

(d) *Individual Traits.*

The germ-plasm of all the individuals belonging to the same species or race contains the same number of Idants and Ids ; and, furthermore, all the determinants, be it from the paternal or maternal side, must be homologous.

Blended inheritance of individual traits, then, would simply depend on the combined action of the determinants from father and mother, which, being equal in number and determining power, would bring about an intermediate result between the characteristics of the parents.

More difficult to explain is the case where the child resembles only one parent—let us say the father. At first sight it seems impossible that the child should have no resemblance to the other parent, seeing that the mother, too, furnishes the same quota of hereditary substance, there being an equal number of Ids in the germ-plasm of both parents. Furthermore, as the child receives only half the number of chromosomes from the father, we must presume that half the number of Ids of the father are sufficient to express his full characteristics. All that can be

said is, that it is so. The child can predominantly resemble one parent only. The cases of hybridization, as quoted already, show that, in the crossing of different species, the characteristics of one parent may be suppressed nearly to complete exclusion, thereby proving that the determining power of the Ids of one parent may fall to zero in the presence of a stronger set of determinants of the other parent. We may in the same way explain the predominant inheritance of individual traits by assuming that the Ids of one parent, though present, do not come to expression in the developing organism. Father as well as child may be predominantly shaped by the influence of the same set of Ids—that is, those derived in each case from the father— while those of the mother remain unexpressed. In Fig. 41, if the black Ids are in each case predominant, the father (second generation) and the child (third generation) would resemble each other, showing the black type exclusively.

Another possibility lies in the fact that the number of homodynamous determinants may be greater in the Ids of the father than in those of the mother, so that, by acting in unison, they would overcome the smaller number of those of the mother.

As the number and power of the homodynamous determinants may vary for each particular stage of the child's development, we find in the same circumstance also the explanation for particulate inheritance of individual traits.

B QUANTITATIVE CONTRIBUTION OF ANCESTORS.

It is generally reckoned that the parents contribute to the heritage of the child $\frac{1}{2}$ each ; each grandparent, $\frac{1}{4}$; each great-grandparent, $\frac{1}{8}$, etc. But though each parent furnishes half the hereditary substance of the offspring, the proportions for grandparents, etc., are by no means necessarily expressed by $\frac{1}{4}$, $\frac{1}{8}$, etc. For if we assume the species to have 16 Idants (see Fig. 41), grandfather as well

as grandmother (first generation) will have 16 Idants each, which number is reduced in their germ-cells to half—*i.e.*, to 8 ; 8 Idants of the grandfather (denoted black) unite with 8 Idants of the grandmother (denoted white) to form the parent (second generation). The germ-cells of this parent will, again, contain only half the number of Idants —*i.e.*, again 8 Idants.   But now the division may separate the Idants in any combination of black and white Idants ; for the line of division may fall in any direction, as indicated
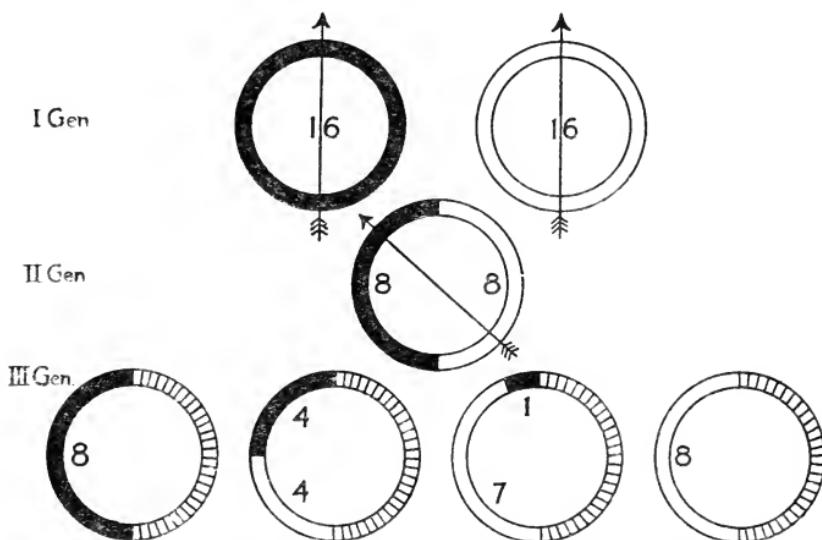
FIG. 41.—CONTRIBUTIONS OF ANCESTORS.   (After Weismann.)

by the arrow in the figure of the parental germ-plasm (second generation).   Thus we may get in the third generation 8 black or 8 white Idants only, or a combination of 7 black and 1 white, 6 black and 2 white, etc., or any other possible combination of black and white Idants, making together 8 Idants.   (These, in conjunction with 8 Idants— the shaded parts—derived from another ancestral line give again 16 Idants as the germ-plasm of the grandchild.) A grandparent may therefore be represented in the grandchild by any number of Idants from 8 downwards to 0

—*i.e.*, the quota of heritage from the grandparent may be anything from $\frac{1}{2}$ down to 0.

The inheritance from more remote ancestors may be worked out similarly.

IV. — *THEORIES OF DEVELOPMENT.*

(a) EVOLUTION VERSUS EPIGENESIS.

We have already seen in a previous chapter that two kinds of theories with regard to the development of the embryo had been advanced : the one asserting that a pre-formed embryo in miniature lay ready in the germ-cell to unfold itself (evolve) at the propitious moment (the Evolution theory) ; while the rival theory of Epigenesis held that the germ-cell created out of its homogeneous contents the embryo anew, organ by organ. That the latter theory was the correct one had been finally established by the aid of microscopical observations of the actual stages of the developing ovum. After this it may seem strange that the old controversy should have been revived in modern times. Still, the problem is not the old one, as this has been finally settled by the test of actual observations, but is a deeper and more fundamental one. We have to deal now, not with the visible formation of the embryo from cells, but with the inner invisible structure of the germ-plasm. If with W. Roux we define " epigenesis to be the new formation of a complexity," while " *evolutio* means the becoming visible of a pre-existing latent differentiation," the new problem resolves itself into the following question : Is there a pre-determined architecture of the germ-plasm, according to which the embryo evolves (the new Evolutio) ? Or is there no such architecture, the development of the new organism being due, not to the intrinsic quality of the germ-plasm, but to external causes (the new Epigenesis) ? The former view, as we already know, is championed by Weismann, while the latter theory has its chief defender in Oscar Hertwig. Weismann maintains that a differential or quali-

tatively unequal (*erb-ungleich*) division of the germ-plasm takes place during development, by which a different set of determinants is allotted to each cell, thus deciding time and mode of its development, though such differences may not be visible with our means of observation.   Only when a cell divides into a mass of cells, all of the same function, does an integral or doubling (*erb-gleich*) division of the nuclear substance take place.   Hertwig, on the other hand, denies the occurrence of a differentiating division altogether on many grounds, which it is impossible to enumerate here in detail.   He holds that all cells are of equal value, it only depending on their relative position to each other what part of the organism arises from them.   Unfortunately, experiments conducted with a view of settling this question have not been decisive either way.   If the hereditary substance of the ovum has a definite architecture, and each cell, as it appears, receives its predetermined part of it, then, if any of the cleavage-cells are removed, the corresponding part of the embryo would be removed with it, and a defective embryo be the result.   Indeed, Roux's experiments on frogs' eggs showed that the removal of one of the first two cleavage-cells leads to a one-sided embryo.   But, on the other hand, experiments by Hertwig, Driesch, and others have given the opposite result, blastomeres (separated cleavage-cells) of the first stages developing into normal though diminutive embryos.   Not only this, but artificial influences, as pressure on the developing ovum, may bring about a change in the order of its cell-segmentation, so that now differently situated cells form tissues previously formed by other cells.   In short, Hertwig considers that " The motor forces of development are not residing in the germ-plasm, but external to it ; they are due to the continual changes in the mutual relations of the cells as they increase by division, and to influences of the surroundings." It is quite possible, though, that in different cases the final differentiation of cells may not occur at the same period of segmentation, so that in the first stages the blastomeres

would be capable of more than one mode of development, which would explain the contradictory results of the experiments. Furthermore, Hertwig himself, as already hinted at, admits that, even from his point of view, " the process of development requires the assumption of the existence of different kinds of germinal material in different kinds of organisms. . . ." " But," he goes on to say, " only such characters are to be ascribed to the germinal substance as are appropriate to the true nature of a cell, but not those numerous characters which come into existence only by the interrelation of many cells and the action of environment." Seeing that the nature of each individual cell is thus made dependent on the quality of the germ-plasm, there seems to be, after all, not much difference between Hertwig's and Weismann's views.

(b) GERMINAL SELECTION.

We are already familiarized with Weismann's idea of the struggle of the determinants, having seen how he uses the idea of the overpowering preponderance of one kind of determinants over others to explain the various modes of inheritance. In the cases mentioned, the struggle takes place in the fertilized ovum during the process of development between two sets of determinants—those derived from the father, and those derived from the mother respectively. But Weismann has extended his idea of the struggle of determinants still further—to the contents of the germ-cells, even before their maturation and fertilization. The determinants combined in the germ-plasm of the various germ-cells of the individual are subject to fluctuations in the food-supply. Indeed, as the germ-plasm reserved for the germ-cells has to grow intensively in order to supply material for the countless young germ-cells of the organism, the determinants of the germ-plasm grow and multiply rapidly. It cannot be assumed that the nutritive stream will be distributed absolutely evenly to all

determinants, and it is conceivable that some will get less nourishment, others more. The former accordingly will become weaker, more ineffective, the latter stronger and more powerful. As the determinants determine the quality of the corresponding part of the body (the " determinate "), this determinate in its turn will vary in accordance with its determinant, and be developed in a lesser degree if its determinant is weaker, and *vice versa*. Not only this, but once a determinant has become weak and varied in the minus direction through what was at first a merely accidental change of the food-supply, its assimilative power will become lessened, thus still further adding to the same deteriorating process, until the determinant, and with it its determinate, may completely disappear. On the other hand, determinants varying in the plus direction would, by drawing nourishment more and more towards themselves, become stronger and stronger, and thus lead to a stronger expression of their own determinates. It is by this process, which Weismann has called " Germinal Selection," that he tries to explain the atrophy (dwindling) of organs and their ultimate disappearance. As Weismann does not admit the inheritance of acquired characters, according to which the gradual dwindling and ultimate loss of an organ is brought about by the inherited disuse of the organs through successive generations, he had to find another explanation for these cases, and advanced for this purpose his theory of Germinal Selection. Furthermore, the same theory enables him to explain the occurrence of highly-developed traits in civilized man, as the musical faculty, etc., which are not useful in the struggle for existence, and could not therefore have been evolved by the process of Natural Selection. For a discussion of these questions, however, we must refer the reader to the books on Darwinism and Natural Selection.

CHAPTER V

I.—REVERSION.

By Reversion or Atavism we understand the reappearance of ancestral traits which have been absent or latent in the race for one or more generations. These atavistic characters must not be confused with phenomena which, though seemingly due to a throwback or reversion, are in reality caused by arrested development. As each individual repeats during its ontogenesis the general stages of the line of its animal ancestry, it will sometimes happen that an organ, when arrested at a certain stage of its embryonic development, will present the type of some ancestral species : thus, a cleft-palate or a hare-lip is due to nothing but to defective union of the two primitive upper jaws, which is a persistent trait in certain lower animals. Such cases are not instances of reversion, for the organ in question is not absent in any one generation, but is represented in each generation in its normally developed form.

In true reversion we may distinguish between those cases where only one generation is skipped, the grandchild taking after the grandparent, and those cases where an individual shows traits of a distant ancestor, often of a different, though related, species.

(*a*) Reversion to Grandparents.

In the crossing of distinct varieties there is a great tendency for the offspring to revert to one of the parent types after a few generations. It is possible that even as early

as the third generation a complete reversion to one of the grandparents may take place. For instance, if a variety A is crossed with a variety B, both having 16 Idants each, (A being designated by black, B by white, see Fig. 42), then the hybrid (second generation) from both will have a germ-plasm of 8A + 8B ; *i.e.*, it will be intermediate in appearance between both crossed varieties.

Each germ-cell of this hybrid will, after the reducing division, contain only 8 Idants, and among them must be
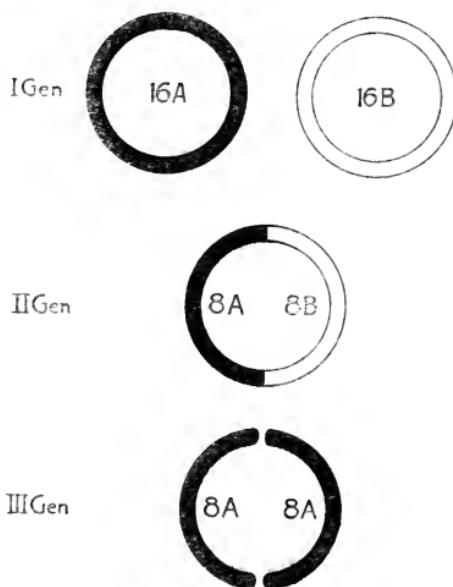
a number of germ-cells with 8 black Idants A. If, now, either inbreeding of these hybrids takes place, or crossing with the old parent form A, any such germ-cell containing 8 Idants A may meet with another germ-cell of the same kind, derived either from the hybrid or from the grandparent form A, and thus lead to a germ-plasm containing once more 16 Idants A. This will produce an individual of the grandparent type A, though, as we have seen, the

FIG. 42.—REVERSION.

hybrid itself was not a replica of the grandparent A, but intermediate between both grandparents A *and* B.

While in the crossing of varieties all the Idants could, for practical purposes, be assumed to be identical, expressing the racial characteristics, in the case of individual traits the Idants would be slightly different in the two parents with regard to detailed individual peculiarities. The explanation of the resemblance between grandchild and

grandparent works out in these cases somewhat differently. As the image* of the individual is always the outcome of the union of two parental strains, the possibility is rarely given that a child may completely resemble one of its parents or grandparents, for in each case the image of the individual is determined by the paternal *plus* maternal germ-plasms. In order that a child may exclusively repeat the image, be it of its father or of its grandfather, we would have to assume that each time the maternal Idants which enter into combination with the paternal Idants are in their effect completely suppressed, which is hardly likely to occur in a series of generations. There-

fore, that the grandchild may exclusively resemble one grandparent —*e.g.*, its grandmother—it is necessary that exclusive inheritance take place successively in grandmother, father, and child. For if we assume A and B (see Fig. 43) to be the Idants of the two grandparents (first generation), then the father (second generation) has the germinal constitution AB, where we must assume A to be predominant over B, so that the father resembles the

FIG. 43.—ATAVISM.

grandfather A only, while the characteristics of the grandmother B are latent and do not come to expression. Some of the father's germ-cells, which contain half the number of his Idants, will contain only the Idants B. These, in combination with Idants D from the mother, will represent the grandchild (third generation). But, in order that the grandchild may exclusively resemble its grandmother B, the Idants B derived from the father will have to be predominant over the Idants D derived from the mother, as the Idants B must also have been the dominant
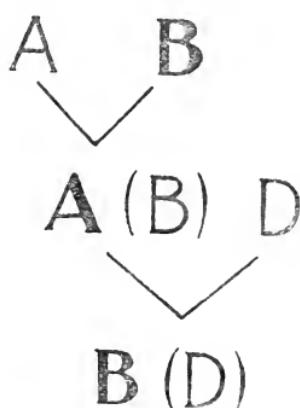
* Image here denotes the sum total of the characters expressing the individuality of each single being (Weismann).

group in the expression of the image of the grandmother herself. In short, in grandmother, father, and grandchild there must take place each time exclusive inheritance ; the image must be expressed by the Idants derived from one parent only, otherwise the Idants added from the other parent would modify the image and prevent complete resemblance. While such complete resemblance is very unlikely, and also in reality very rare, there being as a rule only more or less of a family likeness, resemblance in a certain set of characters is more easily possible, as a majority of Ids of the grandfather may be carried forward to the grandchild, and thus originate the same set of characteristics once more.

$$a\ b\ c\ d\ e\ f\ g\ h\ \times\ i\ k\ l\ m\ n\ o\ p\ q \qquad \text{1st generation.}$$

$$a\ b\ c\ d\ \times\ i\ k\ l\ m \qquad \boldsymbol{a\ b\ c}\ f\ \times\ \boldsymbol{l}\ n\ o\ p \qquad \text{2nd generation.}$$

$$\boldsymbol{a\ b\ c\ l}\ .\ .\ .\ . \qquad \text{3rd generation.}$$
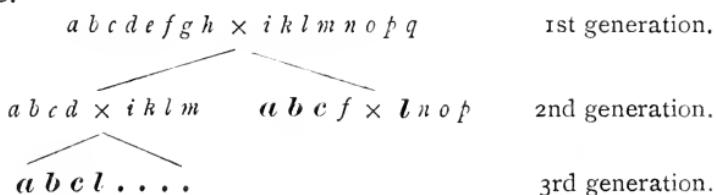
FIG. 44.—INHERITANCE FROM AUNT. (After Weismann.)

In a similar way one could explain resemblance to an uncle or an aunt. In Fig. 44 each individual has eight Idants, the thick letters representing the four predominant Idants, which in each case determine the image of the individual.

In the first line we have the grandfather paired with grandmother ; in the second line two daughters (second generation). One of the daughters has a child (third generation), which, as will be seen from the diagram, has the same predominant Idants as its mother's sister, and therefore resembles her.

(b) REVERSION TO DISTANT ANCESTORS.

We speak of Reversion in its proper sense when an individual belonging to a recent race harks back in certain characteristics to an ancient race, which lies in the line of

its own far-off ancestry. Such cases have been made familiar by the works of Darwin, who, for instance, mentions the zebra-like stripes on the fore-legs of horses, and oftener still of mules ; or the reappearance of blue pigeons resembling the wild rock-dove (*Columbia livia*) among a breed of fancy pigeons : both being evident instances of reversion to the old ancestral type of the respective species.

We can explain such reversions on the ground of Weismann's theory of Determinants in the following manner : We have already seen that the Ids of any species do not all contain identical determinants representative of all the racial characters, but that some of the determinants are survivals of the old stages through which the species passed during its racial evolution. Indeed, such old unmodified determinants will be present in various numbers in nearly every species, because to make a species stable in its characteristics, it is only necessary that a majority of determinants be moulded into the predominant form. A minority of old determinants may well persist, and perchance, through the means of reducing divisions and amphimixis in a series of generations, by which each time germ-cells containing such old determinants would be united, accumulate in the germ-plasm, and thus ultimately come to expression in an offspring. Even if a majority in number should not always be attained, they might still be predominant, seeing that the old determinants are all homodynamous, trying to express the same character, while the other determinants, if very distinct varieties are crossed, would be heterodynamous in their action, and mutually cancel each other. This explains why reversions are most likely to occur after repeated crossings and recrossings with many varieties, because it is then that the old racial determinants are most easily able to assert their combined power against the various heterodynamous new determinants of the many crossed varieties.

II.—*TELEGONY*.

It is a widely accepted belief among dog-breeders that a pure-bred bitch once lined by a mongrel becomes spoilt for further true breeding, it being assumed that the mongrel's influence extends to the offspring the bitch may have from a later mate. This distant effect of one male on the progeny of another male from the same female is termed " Telegony." Many such cases are on record, the most famous one being that of Lord Morton's mare, mentioned by Darwin. " A nearly pure-bred Arabian chestnut mare bore a hybrid to a quagga, and subsequently two colts to a black Arabian horse, which were partially dun-coloured, and striped on the legs more plainly than the real hybrid, or even than the quagga. . . . The hair of the mane resembled that of the quagga, too, being short, stiff, and upright."

Similarly, a white woman, after having had intercourse with a negro, is said to have borne children to a white man which showed some negro peculiarities. It may be said at the outset that in most cases the pedigree on both sides was not fully enough known in order to establish beyond doubt the occurrence of real Telegony.

Many suggestions have, therefore, been made in order to explain away the supposed cases of Telegony. Thus, the characteristics of the progeny from the second sire may have been due to reversion to an ancestor whom the first sire himself resembled. For instance, the occurrence of quagga-like characters in the above-mentioned case may have been nothing but the reappearance of latent ancestral characters, as such are not rare in horses. The resemblance may in other instances be merely coincidence, as cases of Telegony are, after all, very rare. Another explanation, that the first sire leaves on the female a permanent impression, which communicates itself to the offspring of the second sire, is hardly acceptable, because maternal impressions are, as we shall see later on, not proven.

The attempts of explaining Telegony itself have also been various. Thus, a storing of the spermatozoa of the first sire in the impregnated female has been assumed, but then birth *without* a second sire should be possible—an occurrence unknown among higher animals. And, further, it is known that the spermatozoa not used up in the fertilization of the female disintegrate and disappear during the period of gestation. Failing the persistence of the germ itself, the influence of the disintegrated germ-substance has been invoked as an explanation. And, lastly, in the " Saturation hypothesis " the mother's constitution is supposed to be influenced by the fœtus of the first male, which influence reacts on the next offspring. This implies that characters acquired by the mother from her own offspring are transmitted to her next progeny, and we have, as we shall see in a later chapter, no warrant for such an assumption.

III.—XENIA.

Under the name of " Xenia," or guest-gifts, certain cases have been described showing the curious phenomenon of the male pollen influencing the substance of the seed, or even the fruit, *i.e.*, parts of the mother-plant, which do not strictly belong to the embryo itself, and which thus receive, as it were, a gift from the fertilizing pollen. To appreciate this fact, we must point out that the surrounding layers of the plant embryo, which form what is commonly called the seed or fruit, are furnished by the maternal tissue of the ovary. Thus, white-grained maize will, when fertilized with pollen from the blue-grained variety, produce white seeds—*i.e.*, seeds having a white endosperm (nutritive layer) round the embryo, but also a number of blue-grained seeds having a blue endosperm. It would seem that we have here a direct influence of the male germ on the mother. The only explanation possible for Darwin was to assume a migration of gemmules from the fertilized ovum into the surrounding mother-tissue. Since then,

however, a satisfactory solution of the problem has been found in accordance with our knowledge of the nuclear character of hereditary transmission. It was shown that what takes place in reality is a sort of double fertilization. The pollen-grain divides into two generative nuclei, one uniting with the ovum nucleus, forming the embryo, the other fusing with the polar nuclei,* belonging to the mother-tissue, and forming the protective and nutritive layers around the embryo.

IV.—MATERNAL IMPRESSIONS.

It is a time-honoured belief that strong impressions made on the mother whilst carrying will, in some mysterious way, be imparted to the child, and evidence themselves in strange birth-marks, malformations, etc. The mother may have been frightened by a mouse : the baby born shows a brown patch on the skin, having a vague resemblance to the shape of a mouse, and the connection between both facts is taken to be one of cause and effect. It is a true *post hoc, ergo propter hoc*. There is no evidence whatever that such cases are actually due to the mental experiences of the mother during gestation. In most cases it is nothing but a mere coincidence, because birth-marks are fairly frequent, and strange experiences of pregnant women also, especially when a malformation or other defect has to be accounted for. Only striking coincidences, of course, are noted, while the failures are forgotten. All we can say is, that the mother's health has decidedly a general effect on her offspring, and, further, in so far as mental experiences may generally affect her own body, in so much may they affect the fœtus, which is a living part of her. But no cases of special effects reproduced in the offspring can rationally be accounted for, nor have such cases been scientifically demonstrated.

* The polar nuclei of the plant-embryo sac must not be confused with the polar bodies of the maturation of the ovum.

V.—DETERMINATION OF SEX.

The fundamental distinction between the two sexes is the possession of the sex-gland, the male producing sperm-cells, while the female has an ovary with egg-cells. All the other distinctive sex characteristics, as the organs for copulation, or, in the case of the female, those for bearing and suckling the young, are secondary. We have already seen in a previous chapter that the separation of the sexes is by no means absolute. Not only can both sexes in certain species be united in a hermaphrodite individual, but we have seen that even the highest animals pass through an embryonic phase where both kinds of sex-organs are still existent. It is only at a later stage of the development that the sex is finally determined, and this occurs the earlier the higher the organism stands in the scale of life. It follows from this that each being is potentially of either sex. Weismann, therefore, assumes that the germ-plasm contains a double set of determinants—male and female—and that characteristics of either sex come to expression according as the male or female determinants have the deciding influence. By this theory of double sex determinants it is explainable how the transmission of sex characters through the opposite sex is possible, as when the characteristics of the grandfather (beard, etc.) reappear in the son of his daughter—qualities which must have lain dormant in the daughter. In castration, where the sex-glands are removed, the development of the usual sex characters is inhibited, and the latent characters of the opposite sex become apparent.

But we are still faced with the fundamental question : What decides the ultimate predominance of one sex over the other ? At what stage does the determination of sex take place ? We must here point out that it is wrong to regard the ovum, as is often done, as a female, and the spermatozoon as a male, product of the body. Both are, as we have already explained, not complementary to each

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other, but each alone is capable of producing a complete being.

The real cause of sex determination has so far not been found, and we can only give a brief review of the many theories advanced. In this it is best to follow Professor J. A. Thomson's arrangement, dividing the different factors adduced into (*a*) influences of food and other agencies ; (*b*) influence of parents ; and (*c*) internal conditions of the germ.

(*a*) INFLUENCES OF FOOD, ETC.

In the various species the ratio of male to female individuals is fairly constant : thus, in man the proportion of males to females born is about 106 to 100. Now, it has been shown that in many cases the usual proportion of the sexes can be appreciably altered by varying the external conditions of the animals. Thus, in tadpoles, where the sex is determined relatively late, the percentage of females can be raised from 57 to 92 by giving various kinds of flesh diet. The production of female generations can be prolonged in plant-lice by giving them abundant food and warmth. The case of the bee is well known : the larva destined to become a queen is fed with a special diet. If a queen dies, one of the worker larvæ can still be turned into a queen by appropriate feeding. In the little Rotifer *Hydatina* males or females can be reared at will by either raising or lowering the temperature. In man, though many suggestions have been made, no influence of dieting the mother has been found to be of any decided effect.

(*b*) INFLUENCE OF PARENTS.

The age of the respective parents is said to have something to do with the sex of the children. Thus, according to some statistics, in marriages where the husband is the older the offspring are supposed to have a tendency to be preponderately of the male sex, and *vice versa*. On the

other hand, the more vigorous or superior parent is held by some to determine the sex of the children. But, while it is difficult to define what is exactly meant by vigour or superiority, we have at the same time statements exactly the reverse, maintaining that the exhausted soldiers returning from a war have a tendency to beget males.

(c) INTERNAL CONDITIONS OF THE GERM.

In some animals, as Rotifers and Insects, two kinds of eggs exist, the one giving rise to males, the other to females. Often the female egg is distinguished by its larger bulk, in accordance with the general rule that the female, being more sedative and anabolic, is of larger size than the male, as is exemplified also in the great contrast of size between ovum and spermatozoon.

According to the latest researches, there occur in certain insects two kinds of spermatozoa, half their number having an odd " accessory " chromosome, while the other half is without it. The ova, on the other hand, all contain the odd chromosome. E. B. Wilson has been able to show that the fertilization of an ovum by a spermatozoon with the accessory chromosome leads to the production of a female, while the union of an ovum with a spermatozoon without the odd chromosome produces a male.*

In the bee the act of fertilization determines the sex, for the drones spring from unfertilized eggs, while the queen and workers develop from those eggs which are fertilized. In other cases the age of the germ is supposed to have an influence. Thus, K. Düsing argued that young ova have a tendency to produce females, young spermatozoa males, while old germs have the opposite effect. He found herein the cause for the automatic regulation of sex-proportion in the race ; for if there is a scarcity of males, they will fertilize often, their spermatozoa will always be fresh, and

* A Mendelian explanation has been attempted for these cases (see W. Bateson, *Mendel's Principles of Heredity*).

tend to produce males, while, at the same time, the females, being superabundant in number, will have less chance of being fertilized, and therefore, if fertilized, will have old ova, also tending towards a preponderance of the male sex.

We must further point out that identical twins, which arise from a single ovum, are always of the same sex.   It seems, therefore, a very probable conclusion to assume, from the various reasons adduced, that the sex is already fixed in the fertilized ovum, in some cases, perhaps, even before fertilization, though environmental conditions may in other cases have the final determining influence.   In fact, as is only likely to be expected, the different factors mentioned have a varying degree of influence in the different classes of organisms.

CHAPTER VI

THE INHERITANCE OF ACQUIRED CHARACTERS

In turning our attention to the question whether acquired characters are inherited, we are coming to a most important and at the same time hotly debated problem of Heredity. It is, indeed, the foremost issue in the whole subject of Heredity, inasmuch as practical consequences of the most far-reaching extent flow from the answer we give to this question. The whole future of our race, its improvement and betterment, is vitally affected by our decision, whether we affirm or deny the possibility of the inheritance of acquired characters. And it is for this very reason that the point has been so assiduously and so hotly discussed by the leading scientists and still forms the " vexed " question of modern Biology.

I.—THEORETICAL CONSIDERATIONS.

That characteristics acquired by the parent are transmitted to the descendants has been an accepted axiom, which was barely called into question until recent times. In fact, Lamarck's theory of the progressive transformation of the species through the effects of use and disuse takes for granted that these effects wrought on the parent-organism during its lifetime are handed down to the offspring, thus accumulating in ever-increasing ratio in the successive generations. Darwin, though he based his theory of Organic Evolution on Natural Selection, which, through the survival of the fittest, achieves a gradual improvement of

the race and maintains it, Darwin himself still upheld at the side of Natural Selection the Lamarckian principle to a considerable extent. Nay, his theory of Pangenesis, as we have seen, was mainly conceived with the idea of explaining the method by which modifications undergone by the parent through environmental changes could be transmitted to the germ-cells, and thus lead to their inheritance by the next generation. We have already pointed out some objections against this theory. Here we may add that, even if we take the mode of transmission of acquired characters for granted, we are still far from a solution of the problem. For if the cells of the body throw off characteristic gemmules at all stages of their existence, gemmules representing all these stages would accumulate in the germ-cells, and it is difficult to conceive how special impressions made by environmental conditions should be pre-eminent, and be repeated by the germ-cells in exactly the same manner. One would rather expect a general effect of all the influences registered than particulate inheritance of special modifications. Other theories have been advanced by the adherents of the belief in Use-inheritance (as the theory of the inheritance of acquired characters has shortly been called), for instance, by Herbert Spencer, whose system we have already dealt with.

But the theory *par excellence* of this school of thought is the " Mnemik Theory," first propounded by E. Hering in Germany, and independently by Samuel Butler in England. According to this theory, the cells and tissues of the organism retain impressions impinging on them by means of the organic memory, unconscious though it be, which is the attribute of all living matter. The modifications wrought on the body reverberate through the body to the germ-cells, and are there retained as a faint echo, as it were, by means of the mnemic faculty of the germ-cells, which are thus modified in accordance with the original impress on the body. Whether this is so or not, it does not solve the problem under discussion. An explanation of

the inheritance of acquired characters, however ingenious or plausible, is not tantamount to the proof that such inheritance occurs *de facto*. This is the very point at issue, which has to be proved.

Galton was the first of the modern biologists who threw doubt on the evidence adduced in favour of this contention, and he shaped his theory of heredity in accordance with his conviction, as we have demonstrated in a previous chapter. But it is first and foremost Weismann who, led by theoretical considerations, came to an utter disbelief in the long-accepted notion that acquired characters are inherited. He has ever since been the champion of the opposite school of biology, which, disregarding altogether the effect of acquired characters for the evolution of species, finds the explanation of organic changes exclusively in Natural Selection and other collateral agencies.

II.—THE FACTS AND THEIR INTERPRETATION.

Before entering into the full discussion of the question, it will be wise first to clear the issue by defining what are acquired characters. This is the more necessary as a good deal of confusion and useless discussion has arisen from authors applying to the term different meanings. First of all, we must point out that " acquired " in the biological sense is not synonymous with " new." A character may be new for an individual or the race, and yet not be acquired. Thus, the beard in a man is new for each separate individual, but we know that it is part of the male inheritance, and not newly acquired. Or by the union of two different germs a new character may appear, as in hybrids, yet such a character, though new for the race, is not acquired. By " acquired " characters, in the technical sense of the word, we understand " modifications of the body due to environmental or functional changes, and not inherent in the germ." They are what Weismann has called " somatic modifications, in contradistinction to germinal variations,"

the latter being variations which arise in the germ, though their cause may not always be clear to us.   Of such acquired characters (acquirements they have been called in short) there are many well-known instances, either due to environmental effects, as the climatic changes of plants, the sunburnt skin of man, etc., or due to use and disuse, familiar examples being the well-developed arm of the blacksmith and the puny, stunted body of the factory worker.   But in practice it is not always possible to determine in individual cases whether a given character is " somatogenic " (arising in the body), or " blastogenic " (arising in the germ).   In fact, it is impossible for an adherent of Weismann to prove that a given acquired character is *not* inherited, as a negative cannot logically be proved in any case.   All that the controversy, then, turns upon is this : The instances adduced in favour of the contention of the inheritance of acquired characters have to be examined, each on its own merit. As long as it can be shown that another explanation of these cases is possible, they necessarily fail as evidence in support of the contrary opinion.   Indeed, the difficulty is, as Herbert Spencer put it for his school, to find cases " where the occurrence of selection, natural or artificial, can be wholly excluded."

We shall find it most convenient to deal with the several points at issue by arranging them somewhat in the manner Professor Thomson has done in his excellent book on *Heredity*.

(a) INHERITANCE IN UNICELLULAR ORGANISMS.

It has been argued, with an apparent show of truth, that if acquired characters are not inheritable, then the whole elaborate fabric of Organic Evolution falls to the ground, as there would be no means by which the original one-celled organisms could have changed and assumed new forms leading to the more complex and higher stages of life.   Furthermore, experiments have been cited which

go to show that cultures of bacteria may, under altered conditions, undergo transformations which are maintained through a series of generations, though the inducing conditions may long since have ceased. The fact is that unicellular organisms are modified under the direct influence of the environment, but the inheritance of such modifications is not comparable with that in multicellular beings. The change which is wrought in the whole body of the unicellular organism is naturally transmitted to the next generation, because this really is nothing but the mother-organism divided into two halves—soma as well as nucleus. There is no differentiation as yet between body and germ cell. A metazoon derived by a series of cell divisions from a single cell is strictly comparable, not to one generation of one-celled animals, but to a number of such. The process of inheritance involved is, therefore, a different one. In short, while there is inheritance of acquired characters in unicellular beings, this proves nothing for the case of multicellular organisms. Or we can look upon the matter from another point of view, and express the problem in the following way : In one-celled organisms, body and germ being one, acquired characters are at the same time inborn characters ; both kinds of inheritance, somatogenic and blastogenic, are not yet differentiated. In higher animals the problem of acquired versus inborn characters is set for the first time.

(b) MUTILATIONS.

It used to be a favourite argument of the defenders of the affirmative side to quote cases of mutilations which had been inherited, and were therefore considered incontrovertible proof in favour of their contention. Thus, a cat had accidentally lost her tail, and given birth to a tailless kitten ; and similar cases of that sort. It has been found that none of these cases could stand scientific examination. Even where mutilation has been practised for ages for

ritual purposes, as in circumcision, etc., no permanent effect has resulted. Experiments made with the same object in view all proved futile. Weismann cut off the tails of mice for generations without achieving so much as a shortening of the tail, not to speak of a complete loss of it. The only experiments in favour of the positive assertion are the well-known ones by Brown-Séquard on guinea-pigs. By severing certain nervous tracts in the animals, he produced pathological changes, such as epilepsy, paralysis, etc., which in a small percentage of the cases reappeared in the offspring. These experiments have been repeated with by no means the same uniform result. Furthermore, Brown-Séquard's own cases seem to many scientists not sufficiently distinctive to afford unequivocal proof. As the matter at present stands, mutilations and the like form the weakest point of the armoury of the upholders of the inheritance of acquired characters.

(c) Congenital Traits.

There is a good deal of confusion in the average mind between congenital traits and inherited characters. The term " congenital " is taken by many to be identical with " inherited." But a character may be congenital—*i.e.*, be in evidence at birth—and yet not inherited. As each being starts its independent existence from the moment the parental germ-cells unite in the act of fertilization, anything which happens to this being from that moment onward by influences external to it must be reckoned as an acquired character, the only difference being that congenital modifications are acquirements occurring *in utero* before the actual birth. The mere act of birth cannot, and does not, alter the organic relationship between body and germ cells of the individual. In fact, we may have inborn traits which are blastogenic, due to arrested development of the germ, as hare-lip and other malformations ; and, on the other hand, defects, malnutrition, etc., due to dis-

turbances within the uterus, caused, perhaps, in the last instance by the abnormal condition of the mother. We have to guard against the mistake of holding without further inquiry every character to be inherited, merely because it is congenital, as we may thus be led to reason from a false assumption.

(d) Germinal Variations.

There is a series of phenomena which at a first glance seems to lend strong support to the contention that acquired characters are inherited. In these cases we find characters which are certainly inherited. But, though they may easily be taken as somatic modifications, and are generally explained as such, yet it is possible to put another interpretation on them.

Instances of this sort are found in certain habits of plants and domesticated animals. Thus, the Golden Rod (*Solidago virgaurea*) flowers earlier in the Alps than in the Lowlands, and retains this precocity even when transplanted to lower regions. This has been claimed as a proof for the inheritance of acquired characters. It may well be, however, that the precocity of the Alpine plant is not an acquirement at all, but has become established in the Alps as a germinal variation through natural selection. Similarly the sporting instincts of dogs have been adduced to show that the effects of use are inherited. For it has been found that young dogs are born with traits their parents acquired, and that these traits can be intensified in successive generations. But even here matters are not quite so simple as they at first appear. In the first instance, only certain breeds of dogs are fit for definite domestic purposes, showing that there is an innate disposition in the different breeds of dogs for certain kinds of training, which, of course, can be improved in each individual by constant practice. These sporting qualities, being natural variations in certain breeds of dogs, and being merely directed towards certain

requirements of the trainer, are, of course, inherited. The further fact that a constant improvement in successive generations takes place may just as easily be due to artificial selection as to the effect of use-inheritance, for it is well known that dog-fanciers breed only from their best dogs. Indeed, this is the method employed by all breeders for the improvement of their stock, which applies as much to sporting qualities as to other points.

There is another set of factors—the effects usually attributed to the influence of civilized life—which are believed to yield strong evidence for the positive school. Thus, Spencer mentions the short-sightedness of the studious townsman, especially German ; the small hands, jaws, and teeth of modern man ; the thick sole of the feet, which is already distinct in the new-born infant : all features, evidently acquired as an outcome of modern life, and certainly inherited. But here the same argument applies as before. The characters are inherited, no doubt, but are they acquired ? As present-day competition does not depend so much on physical excellence of eye, hand, or jaw as on intellectual qualities, the individuals with defective eyes, smaller jaws, etc., would have as much chance of surviving as their betters, which in itself would lead to a greater number of progeny of that type. Or to put it another way, germinal variations cropping up in that direction, not being detrimental in the struggle for life, would not as hitherto be weeded out any longer. A state of " Panmixia " would ensue, as Weismann termed it. Deterioration would set in and continue with the aid of Germinal Selection (as we have learnt already), until, overstepping the limit and becoming dangerous to the individual, it was checked by Natural Selection. The history of the little toe gives clear proof that this interpretation is the correct one. The dwindling of the little toe in civilized man has been attributed to the wearing of boots ; but since it has been found in tribes which go barefoot, it can only be ascribed to a natural tendency of the little toe

to become smaller—*i.e.*, to germinal variation. It has often been argued that the races of man living in different latitudes are what they are on account of the climatic conditions in which they live. It is true climatic influences have some effect on the organism, as we shall see later, but these are not inherited. How if we turn the argument round, and say only such races survive in certain regions as can acclimatize themselves to the surrounding conditions ? Plenty of evidence could be adduced in support of this contention. We know that white men cannot survive in certain climates, though the black races thrive in the very same regions.

In short, when a character is inherited it does not follow that it was acquired in the first instance. It may well have been originally a germinal variation. So long as such cases can be explained in this manner, they cannot be one-sidedly adduced as evidence in favour of the transmission of acquired characters.

(e) Acquirements.

While in the cases just mentioned we had characters doubtlessly inherited, but originally not acquired, we now deal with phenomena of the reverse order. Here the characters are certainly acquired, but the doubtful point is whether they are inherited. Instances of this kind are furnished by those cases where organisms brought into new surroundings become changed, this change being shared by their offspring. Thus, we have experiments made by Professor Nägeli, who transplanted Alpine plants from their original habitat into rich soil at the Munich Botanical Gardens, and found that they changed their appearance, this change continuing for a considerable number of generations. It is well known that sea-plants have certain characteristics, are more hairy than inland plants, and so forth ; that desert plants have thick fleshy leaves to guard against evaporation. Now, though it is true that the

characters are due to these causes, and reappear generation after generation, and may even to a certain extent be intensified with time, that by no means proves that these characters are inherited. On the contrary, there is evidence to show that the same character is merely re-imposed on each successive generation, as it is exposed to the same environmental conditions. It is, in other words, an individual acquirement, re-acquired by each following generation. This follows clearly from the fact that when the plants mentioned were taken back into poor gravelly soil they at once lost their assumed character, and once more presented the appearance of the original Alpine plants. If the acquired character had actually become part and parcel of the individual inheritance, it should have persisted for at least some generations after retransplantation of the plants into their normal habitat.

There has been a good deal of discussion about the physical degeneration of the people. It has been said that, on account of the unhealthy and wretched conditions the poor have to live in and to work under, the physique of the modern worker has deteriorated to an alarming extent. There is no doubt, the present-day slum and factory life has a most deleterious effect on the individual, but whether such bad result is in itself transmitted to the children is by no means decided. There is nothing to show that the progeny of such individual, if removed early enough into healthy surroundings, would not grow up perfectly sound and normal. The stunted and weakly appearance of such children can easily be accounted for in another way. Firstly, the children of the poor are sub-jected from the very first days of their lives to the same unwholesome and grinding conditions of existence as their parents ; and, secondly, the state of the mother, who is generally underfed and overworked, is bound to have a harmful influence on the child even before birth. Con-genital weakness is in most of these cases nothing but the

result of intra-uterine under-development, due to insufficient nourishment, and is not necessarily due to an inherent defect of the germ.

(f) ENVIRONMENTAL INFLUENCES ON GERM-CELLS.

There are other cases similar to those just described, where certain environmental influences, acting on the individual, are held to yield decisive evidence of their being inherited. To these belong the variations of certain butterflies due to climatic conditions. For instance, exposure of the *Vanessa* butterfly during its pupa stage to cold or heat alters the colouring of the developing butterflies in accordance with the natural variety prevalent in the northern cold or southern warmer region. Not only this, but some of the progeny show a tendency in the same direction. While this seems conclusive evidence against Weismann, he none the less finds that even these cases are not at all so simple as they at the first glance appear. First of all, it is possible that the germ-cells are influenced by environmental changes along with the body harbouring them. Furthermore, the variations resulting from the experiments were not a completely new creation, but only showed a tendency more or less towards the northern or southern coloration of the butterflies. As in some cases it could be shown that the changes induced by cold were nothing but reversions to older phyletic stages of the same species, it is not going too far to conclude that the influence of the temperature did not in reality change the germ-plasm, but only acted as a stimulus for the reappearance of certain sets of older determinants still present in the germ-plasm. We have here, then, the simultaneous influence of the external conditions acting in the same direction on the wing determinants of the parent pupa and of its germ-cells.

The example of malnutrition of the factory worker quoted already in the last paragraph may also be cited here. The effects may be all due to harmful influences acting on the

embryo-in-being either before or after birth. But in addition to this, the deleterious influence of parental conditions may affect the germ-cells themselves. It is only too apparent that slow poisoning or chronic wasting of the body is bound to react on the germ-cells in an injurious manner. But while it must be admitted that the germ-cells may in a general way become deteriorated through these conditions, leading to under- or mal-development of the germ, there is no reason why such effects should repeat exactly the results wrought in the parent.

(g) External or Social Inheritance.

We now come to the final argument brought forward by the adherents of the positive side for the inheritance of acquired characters. They point, and apparently with some show of justice, to the effects of culture and learning, not only on the individual, but on the generations following, ascribing the moral and intellectual progress of civilization to the transmission of these very qualities acquired by the parents. But here once more it has yet to be proven whether these characteristics, though admittedly acquired, can be said to be inheritable in the true sense. There is a great mass of opinions, feelings, and thoughts handed down from age to age, each generation receiving from the previous one, and standing, as it were, on its shoulders ; but whether such mental experiences become, as Spencer would have us believe, ingrained into the individual consciousness —in other words, whether such experiences are inherited biologically—is just the point at issue. To try to prove the inheritance of acquired characters from cases where the inheritance itself is doubtful is evidently futile.   Indeed, we may look upon the transmission of these social acquirements as merely an external one, a handing down of customs, conventions, etc., from generation to generation, which does not necessarily imply any intrinsic change in the mental and moral qualities of the people.   " The

results of man's external heritage are often such," says Professor J. A. Thomson, " as might have come about if acquired characters *were* heritable." On the other hand, we shall see presently that progress is by no means impossible if the idea of use-inheritance be excluded.

III.—CONFUSION OF THE ISSUES.

Seeing that all the instances brought forward as proofs of the inheritance of acquired characters are capable of another interpretation, we are driven to the conclusion that the positive contention has, to say the least, not been made out. On the contrary, the evidence rather tends into the opposite direction. For, as we cannot disprove a negative, its validity can only be admitted when it has positively been shown to be a fact. If the Lamarckian position is still held so widely, it is to a great extent due to a confusion of thought with regard to the issues involved.

(a) Evolution and Development.

One of the fundamental mistakes made by beginners in this question is that they confuse Evolution with Development. Though a thorough-going adherent of Weismann refuses to recognize use-inheritance as a factor in the development of the race, he nevertheless admits, as every scientist necessarily must do, the effect of use and environment on the *individual*. The individual organism, though endowed with a given heritage, cannot bring this potentiality of its being into existence unless proper conditions favour its development. The seed may be there, but if the soil and sunshine are missing it will not spring forth. Normal development is possible only under the appropriate stimulus. If the limb of an infant becomes paralyzed, and can no longer be moved, we find it remains stunted in growth. Nay, more, the reaction of a part may vary according to the kind of stimulus falling on it. Thus the ivy grows leaves

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on the side exposed to the sun, but will produce rootlets on that side if turned away from the light. Innumerable adaptations of this kind exist among plants, known as Heliotropism, Geotropism, etc. Animals, too, have this power of adapting themselves to circumstances, as is evidenced by the change of colour in certain caterpillars in accordance with their surroundings, as shown by E. B. Poulton.

But—and this is the important point to grasp—all these phenomena are nothing but reactions of the individual to its surroundings, and do not concern his progeny. The question in each case is : Are these adaptations inherited ? do they form a factor in the production of the race ? This is a different question altogether, which we are now going to discuss.

(b) LAMARCKISM VERSUS NATURAL SELECTION.

It is often assumed by laymen that evolution is possible only on the assumption that the improvements undergone by the parents are transmitted directly to the offspring, thus leading to a gradual progress in ever-accumulating ratio. This is the position taken up by Spencer, and was the original theory of evolution propounded by Lamarck himself. But though this school still survives, we must not forget that Darwin, in his *Origin of Species*, formulated a new theory of organic evolution, that of Natural Selection, and it is this theory which is now generally accepted by the scientific world. According to this theory organisms change ; they vary, and those varying in a favourable direction have the advantage over their fellows in the struggle for existence, and survive, while the less favoured individuals die out. As this process goes on unceasingly, generation after generation, a gradual persistent improvement of the race takes place. This theory explains organic evolution without committing itself to the inheritance of acquired characters, an assumption which, as we have seen,

is far from being verified. Darwin himself, it is true, accepted the Lamarckian principle to a certain extent for special cases which seemed to him most easily explained on that principle, but Darwinism itself is the theory of " Natural Selection." We cannot here go farther into the problem, which belongs properly to the subject of evolution. But one thing is clear. Evolution is possible without the inherited effect of acquirements. More than this, seeing that the inheritance of acquired characters, which forms the basis of Lamarckism, is by no means established as a fact, as we have tried to show in full, we cannot escape the conclusion that at the present juncture of the controversy Natural Selection remains the only workable theory.

CHAPTER VII

THE INHERITANCE OF DISEASE

Though in practice we may distinguish between health and disease, there is in reality no sharp division between them. Nature does not care about any such categories as we may put up in the abstract. Indeed, the arguments on the inheritance of disease would fall naturally under the different heads we have discussed in the previous chapter.

If we discuss diseases separately, it is merely in order to give greater emphasis to a subject of such vital and practical importance.

I.—GENERAL ARGUMENTS.

The general arguments about the inheritance of disease resolve themselves very much on the question whether such are inheritable or not. In other words, we have the discussion once more whether acquired characters—in our instance, acquired diseases—are inherited or not. For this purpose we have to discriminate, as previously, which diseases are acquired and which inborn.

(a) Congenital Diseases.

We must in the first instance carefully distinguish between congenital diseases and diseases inborn. Congenital diseases may be inborn or they may be acquired

before birth. In the latter instance, the cause of the disease may be either the unhealthy condition of the mother reacting on the child, or it may be ante-natal infection by a specific microbe. A congenital disease, because it is in existence already at the moment of birth, is for that reason by no means inherited in all cases. It is especially necessary to guard against this mistake in the cases of certain contagious diseases. In these cases the infection of the child may either take place through the mother *in utero*, or the germ itself—either the ovum or spermatozoon—may have been carrying the infective agent, which shows its effects only during the development of the embryo. Thus, congenital syphilis is not an inherited disease, but is merely due to ante-natal infection from either parent. Congenital tuberculosis is very rare, though both mother or father may suffer from this disease.

(*b*) Inborn Diseases.

Inborn diseases are those which have " their physical basis in the germ-plasm of the parental sex-cells." Germinal infection is, as we have already pointed out, a mere infection, and has, as such, nothing to do with intrinsic changes of the germ. Abnormal peculiarities and defects of the germ may arise spontaneously—*i.e.*, without our being able to assign a cause for them. Certain malformations—idiocy, colour-blindness, etc.—are such instances of pathological germinal variations, and are, as such, of course inheritable. (They need not necessarily be inherited in every case ; that depends, as we shall see later, on the distribution of diseased determinants among the progeny.) The difference in the inheritability of acquired and inborn diseases comes out strikingly in Deafness, as quoted by Professor J. A. Thomson. There is a distinction to be made between congenital (inborn) deafness and accidentally acquired deafness due to diseases during childhood. The

percentage of deafness among children in cases collected by E. A. Fay was as follows :

	Percentage of Deaf Children.
Both parents congenitally (inborn) deaf	25·9
One parent congenitally deaf, the other accidentally deaf	6·3
One parent congenitally deaf, the other normal ..	11·9
Both parents accidentally deaf	2·3
One parent accidentally deaf, the other normal ..	2·2

This shows definitely how great the inheritability of inborn deafness is. Acquired deafness seems to make no difference to the children, seeing that we have only a small percentage of deaf children (2·3 per cent.) from accidentally deaf parents (not more than would be expected in an average population) ; and, furthermore, where one parent is congenitally deaf, the percentage of deaf children is actually higher in those cases where the other parent is normal than in those cases where he is accidentally deaf.

There are a number of diseases which can hardly be said to be inheritable in the ordinary sense. Tuberculosis is due to a bacillus ; none the less, it is now a generally accepted fact that a predisposition, consisting of a certain " vulnerability of the protective epithelium," is an essential factor for its acquisition. Gout and rheumatism, too, are such constitutional diatheses to which certain persons are heir and which need only an additional external stimulus— the spark in the powder magazine—in order to break out in full force. Insanity and the various forms of neuroses belong to the same class. Though we cannot define each time in what this predisposition consists, we know that under given conditions only certain people, evidently predisposed, fall victims to these diseases.

(c) Reappearance of Disease.

A disease may be acquired by the parents, but the re-appearance of the same disease in the children by no means signifies that it is inherited. It was said of tuberculosis that it is strongly inheritable, because it was found that children of phthisical parents were very subject to the ravages of that disease. Now, congenital tuberculosis is very rare. From this alone it is evident that tuberculosis, as such, is not easily transmitted. If the children of affected parents show the disease so frequently, it may well be due to the fact that they are constantly exposed to the contagion, not forgetting that they may have inherited a bias towards the tubercular infection. We must carefully distinguish between a disease re-acquired by each successive generation and one that is inherited in the strict meaning of the word.

(d) Secondary Effects of Disease.

A mistake similar to that last mentioned is often made by confusing the inheritance of a disease with certain secondary effects of the same in the offspring. Great disturbances of the parents' health through chronic ailments, cumulative slow poisons, etc., are bound to affect the germ-cells unfavourably, so that the progeny arising from them will grow up weak, or even diseased. Parents with a strong neurotic taint or addicted to alcoholism will often beget children liable to mental and nervous disorders. The resemblance between the condition of the parents and that of the children would seem to point to an inheritance of the disease ; but as the progeny of such parents may show a variety of ill effects produced by the parents' diseased state, the resemblance to the parental disease is only an accidental one. An unstable condition of the germ will result very often in a deranged mental and nervous equilibrium of the growing individual.

II.—SPECIAL DISEASES.

As we are dealing with the subject of diseases only from the biological point of view, it would be useless to give an exhaustive list of diseases, inherited and acquired. We shall only mention such diseases as bear on the problem under discussion and are of interest to the general reader.

(*a*) PREDISPOSITIONS.

We have already pointed out that in a certain number of diseases what is inherited is not the disease itself, but a pre-disposition towards it. To this class belong tuberculosis, gout, rheumatism, etc., where, given a constitutional weakness towards such disorder, the disease is easily brought into manifestation by some additional external factor ; in the case of consumption by the infection with the tubercle bacillus, in gout and rheumatism by other harmful agencies. Similarly, it can be asserted with reason that insanity and other nervous disorders are generally due in the last instance, not to shock or other external disturbing influences, as so often asserted, but to the inherent unstable equilibrium of the nervous system of the individuals affected. Unfortunately, such nervous disposition may run in families, and is to a great extent inheritable, though it may assume in the various members of the family different forms. Hysteria, epilepsy, mania, imbecility, etc., may all be signs of the same degeneracy, which fact furnishes the best proof that what is inherited is not a specific disease, but a general tendency towards neuroses.

(*b*) INHERITED DISEASES.

Of inherited diseases we mention only two, which have a special interest from the curious phenomena connected with them. One is colour-blindness, or Daltonism (called so after the famous chemist Dalton, who himself suffered

from it and described it) ; the other is hæmophilia, or the " bleeder disease." The latter condition is due to a strange anomalous perviousness of the bloodvessels, which makes individuals suffering from it liable to severe, often uncontrollable bleeding on the slightest provocation, be it a small cut or the drawing of a tooth. Both affections show a curious manner of inheritance. Only male members of the affected family inherit the disease. But though the females are free from the disease, they transmit it to their
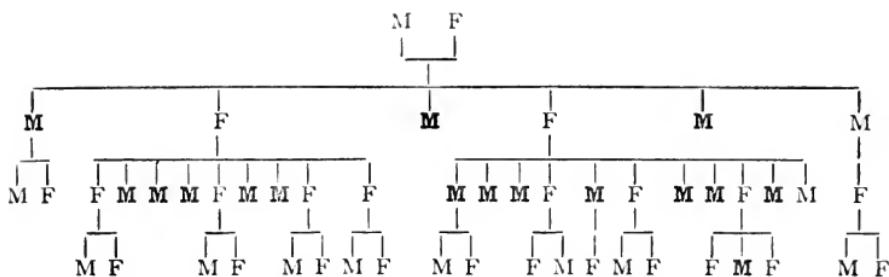

FIG. 45.—PEDIGREE OF BLEEDERS.

(*From J. A. Thomson, " Heredity."*)

The black letters indicate the " bleeders."

male progeny. The above is a pedigree of such a " bleeder " family, given in Thomson's *Heredity*, the thick letters indicating the affected subjects or " bleeders."

(c) ALCOHOLISM.

We deal separately with alcoholism for a twofold reason. Firstly, the subject is of such vast practical importance that too much emphasis cannot be laid upon it. Secondly, there is a good deal of ignorance and misconception with regard to this question, which is not at all conducive to a proper understanding of the " drink problem."

Drunkenness is generally looked upon as if it were an entity. Some would call it a trait of character, others a disease. It is neither. The habit a person may have of

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partaking of alcohol is just as little a character trait or a disease as the custom of taking coffee or tobacco. What leads to drink may be a disposition, either normal or pathological, in a given individual. In one man it may be a weak will, giving way under temptation ; in another, a strong passion coupled with an abnormal craving for stimulants. This has carefully to be distinguished from the result of that disposition, which is the alcoholic state and its consequences. The causes of alcoholism—*i.e.*, those motives and influences which lead men to drink—are outside the scope of our discussion. We deal only with the results of alcoholism, its effects on body and germ cells. Seeing that inebriety is not a character trait nor a disease, it can naturally not be inherited as such. What may be and is inherited is a lesser or greater predisposition leading, under certain conditions, to the taking of strong liquor.

That alcohol, when taken in excess, exerts a most dele-terious influence upon the individual is an admitted commonplace ; but whether the effects of such abuse are inherited by the progeny is open to great doubts. Not that evil results of chronic drunkenness on the children of drunken parents can be denied. Degeneration in the families of drunkards is only too patent a fact. But the question is : What is the real interpretation of the observed facts ?

We must, in the first instance, as we have already pointed out, not confuse the issue by regarding alcoholism as inheritable, because the propensity to drink, which leads to alcoholism, may be inherited. If, notwithstanding, there is the general impression that alcoholism of the parents is transmitted to the children, this is due to the fact that inheritance is simulated through the operation of the same causes as we have already discussed in the section dealing with the inheritance of acquired characters and the inheritance of disease.

We have, first of all, the effect of the alcohol, if the mother is a drunkard, on the foetus. As the alcoholic

poison is circulating through the maternal and infantile system at the same time, its deleterious influence, so visible in the mother, must also make itself felt on the child. Furthermore, the germ-cells themselves of drunken parents, being chronically soaked with alcohol, must be poisoned just as much as all the other organs of the parental body. This must necessarily lead to a pathological disturbance of the germ, and result in abnormal development of the offspring. Now, the children of inebriate parents by no means exactly repeat the morbid conditions of their parents. All we find is abnormal development, chiefly applying to the most sensitive structure of man, the nervous system. We see a host of nervous disorders, a certain nervous instability expressed in lack of control, over-excitability, epilepsy, dementia, etc. We note general effects of the influence of alcoholism rather than particulate inheritance.

If, nevertheless, the progeny of such parents contribute largely to the number of drunkards—drunkenness running in families—this is due to two factors.   In the first instance, persons of weak, unstable, nervous equilibrium will easily yield to temptation, especially if they happen at the same time to be burdened, as is only too likely, with an additional inborn disposition towards the taking of stimulants. Further, these very individuals, ready to fall a prey any moment, are, as regards drink, in the worst possible surrounding.   They have not only the example from their parents and comrades, but mostly active inducement to take intoxicants.   A ready disposition, nervous instability, and an unpropitious *milieu*, all conspire to make the children of drunkards drunkards again.

(d) Immunity.

Immunity is the reverse condition of disease.   It is a bodily state which insures the individual against the attacks of certain infectious diseases.   The immunity is

always specific—*i.e.*, it holds only for any given disease : smallpox, diphtheria, etc.   Immunity from one disease does not protect against another.

Immunity may be acquired or inborn.   In the first case the acquired immunity may be natural, as when a person passes through an illness and acquires, in consequence thereof, freedom from the same disease for a certain period of his life (*vaccinia* or cowpox), or, may be, for the whole remainder of his life (smallpox) ; or the immunity may be artificially induced by various methods—vaccination, serum treatment, etc.   On the other hand, immunity against certain infections may be an inborn characteristic in some individuals, who, though exposed during an epidemic to the contagion, yet never contract the disease. It is a noteworthy fact that the various animal species often show immunity from particular diseases, the diseases differing in the different species.

It would be going too far to enter here into details as to what immunity exactly is, or in what way the different means of artificial immunization act.   Be it said shortly that the immune person has the power to resist the influence of the noxious microbes or their poisonous products by antidotes which accumulate in his own system.

The question at issue once more is : Is acquired immunity inheritable, and how has the natural immunity from certain epidemic diseases which seems to have arisen been brought about ?   Here again we have two possibilities.   Either the immunity acquired by the overcoming of the disease itself has been transmitted to a greater and greater number of individuals, or natural selection has been at work weeding out those most susceptible to the disease, whilst leaving those for propagation who have a natural resistance against the disease.

That acquired immunity is inherited is unlikely after all we have already adduced against the inheritance of acquired characters and diseases, nor has it so far been proved to be a fact.   Immunity may be transmitted by

the mother directly to her infant *in utero*, but such process, as we have already seen, is not to be confused with inheritance proper. On the other hand, much evidence has been adduced to show that natural selection has been at work in evolving in certain regions immune populations, as, *e.g.*, the negroes, who are relatively immune from yellow fever and ague. Infectious diseases introduced for the first time among savage tribes assume their most fatal form, which is evidently due to the fact that no natural immunity of any degree against the introduced disease has been evolved as yet in such tribes. Similar arguments hold, according to some authors, with regard to alcoholism. Here, too, if a certain increase of sobriety among some races has taken place, it is, as Archdall Reid put it, " in proportion to the length and severity of their past experience of the poison." The individuals with the greatest craving for alcohol succumb quickest to the ravages of alcoholism, leaving a population less inclined for strong drink, and becoming gradually steadier and soberer in consequence.

III.—A THEORETICAL INTERPRETATION OF DISEASE.

The inheritance of disease can be made clear, as Professor H. E. Ziegler has shown, by means of the theory of Determinants. If we imagine the tendency to disease represented in the germ-plasm by tainted chromosomes, then the taint will be transmitted in accordance with the process of the reducing division and fertilization of the germ-cells. As the reducing division always removes half the number of the chromosomes, the germ-cells for the next generation will vary as to the number of tainted chromosomes they contain. The union with a second germ-cell, also containing a lesser or greater number of tainted chromosomes, will finally determine the number of diseased chromosomes present in the fertilized ovum. A small number of such chromosomes is less likely to express itself as actual disease than a large number, and so on.

Altogether, the same considerations will weigh that we have already discussed in the crossing of different strains. The following diagram, given by Professor Ziegler, will make the matter clear :

Father—with marked taint, inherited from his father and mother, as shown by the dark chromosomes—13 out of 24.

Three mature sperm-cells showing three different combinations
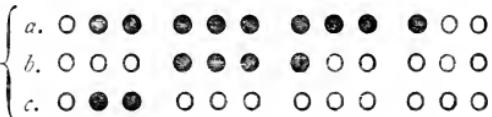
Mother—normal, though with a latent taint, inherited from her mother, as shown by the dark chromosomes—4 out of 24.

Three mature egg-cells showing three different combinations

FIG. 46.—INHERITANCE OF DISEASE. (After Ziegler.)

(From J. A. Thomson, " Heredity.")

IV.—CONSANGUINITY.

There is a general impression, since Darwin has shown that continued inbreeding among plants and animals has a deleterious effect on their fertility and general vigour, that marriages among near kin are unhealthy, and therefore to be avoided. Prevalent though this idea is, it is hardly borne out by scientific facts. It is true that, according to some investigators, signs of degeneration have been found in certain closely inbred populations, but, on the other hand, in other cases no such bad effects could be found. The evidence, as far as it stands at present, is not conclusive either way. All that can be said on this question

to-day is that where there is a taint in the family this is likely to be increased by the mating of two such affected individuals, while, on the other hand, with a healthy stock inbreeding seems to have no harmful effect whatever. This is only what would be expected. Remembering the theoretical explanation of disease given in the previous section, it becomes evident that when both parental germs are affected their union will increase the number of diseased chromosomes. But it can hardly be conceived how disease is going to enter the fertilized ovum if neither of the original two parental germ-plasms is affected. As there are hardly any families in which there is not some taint or other, close intermarriages are likely to accumulate the same taint in certain individuals. It is therefore on the whole safer that no close inbreeding take place, unless it can be made certain that the stock is absolutely healthy. In short, consanguinity is harmful in tainted stocks, but harmless in healthy stocks.

CHAPTER VIII

I.—HISTORICAL.

A GREAT number of experiments on the effects of crossings
of plants and animals had been made by the old school of
hybridists, but without any definite outstanding result.
It was reserved for an Austrian Abbot, Gregor Johann
Mendel, to make one of the most fundamental discoveries
in the whole field of Heredity. Mendel, who had under-
taken a most laborious and prolonged series of hybridization
experiments in the garden of his monastery, chiefly on the
edible pea (*Pisum sativum*) and *Hieracium,* was enabled to
formulate a law of inheritance of these hybrids which bids
fair to become one of the corner-stones of the whole science
of Heredity. The subject of his paper, published as far back
as 1866 in a small provincial journal, passed unnoticed,
and had been wellnigh forgotten, when it was rediscovered
independently in the year 1900 by the botanists De Vries,
Correns, and Tschermak. Since then Mendel's experiments
have frequently been repeated and found to be correct, and
his ideas have been extended to many fields of inquiry.
Mendelism, as this branch of study has aptly been called,
has, in fact, become one of the most important and valuable
factors in our knowledge of inheritance.

II.—MENDEL'S LAW.

When two kinds of the edible pea (*Pisum sativum*) are
crossed with each other, one producing yellow seeds, the

other green seeds (it does not matter which forms the male
and which the female of the parent generation P), their
hybrid offspring (called the first filial generation F_1) will all
yield pods with yellow seeds. That is, yellow is " domi-
nant " over green. When these yellow peas (F_1) are inbred
among themselves, yellow *and* green peas appear once more
in the second hybrid generation (F_2) in a definite pro-
portion—viz., three yellows to one green—showing thereby
that the individuals of the F_1 generation were not pure
yellows, but that in some of them green was latent, or, as
Mendel termed it, green is " recessive." Now, on further
inbreeding of the green and yellow peas of the F_2 generation,
each kind separately, it is found that the green peas breed
true, producing only green peas again for any indefinite
number of generations. But the yellow peas of the F_2
generation, when inbred, are of two kinds—one part again
produces only yellow peas, breeding true throughout all
successive generations, while the remaining two parts of
them produce yellow *and* green peas, again in the pro-
portion of three yellows to one green. This third filial
generation (F_3), when further inbred (each kind separately),
in a similar way repeats the same phenomenon : the green
breed true, while the yellow once more can be divided
into one part of true breeding yellows and two parts of
impure yellows, which again yield yellow and green, and
so on.

If we denote the yellow dominant parent by D, and the
green recessive parent by R, we get a hybrid offspring F_1,
which can be denoted by D(R), R being in brackets to
show that it is recessive to D. The hybrid D(R), being in
appearance like D, gives, when inbred, $3D + 1R$. But the
3 D, when propagated, show that they can be separated
into 1 D + 2 D(R), D being pure dominants, while the
2 D(R) once more, when inbred, can be differentiated into
3 D + 1 R, etc.

We get, accordingly, the following scheme of Mendelian
inheritance :

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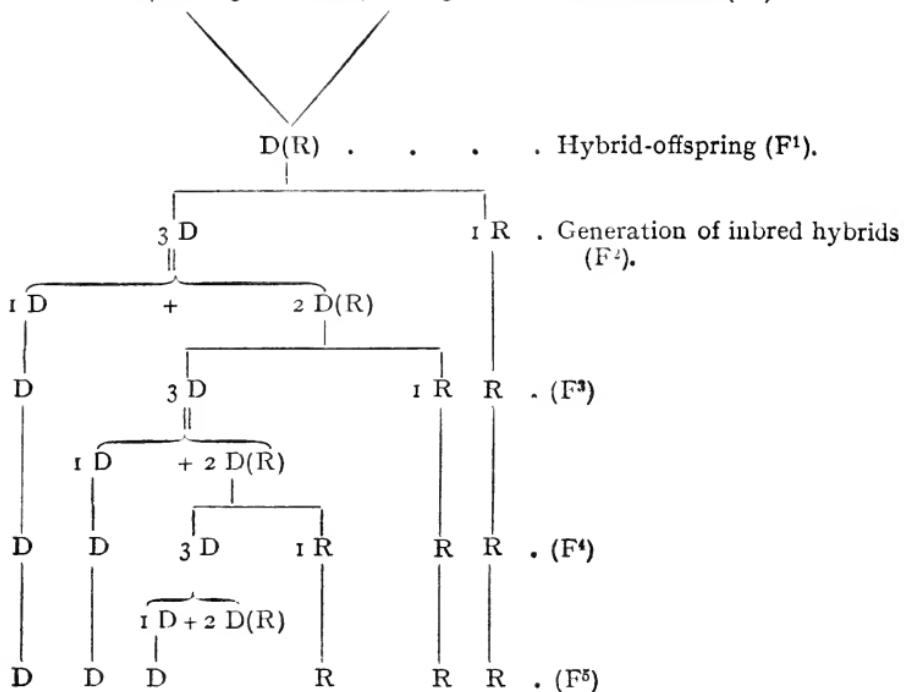
FIG. 47.—MENDELISM.

(*From J. A. Thompson, "Heredity."*)

Or more shortly :
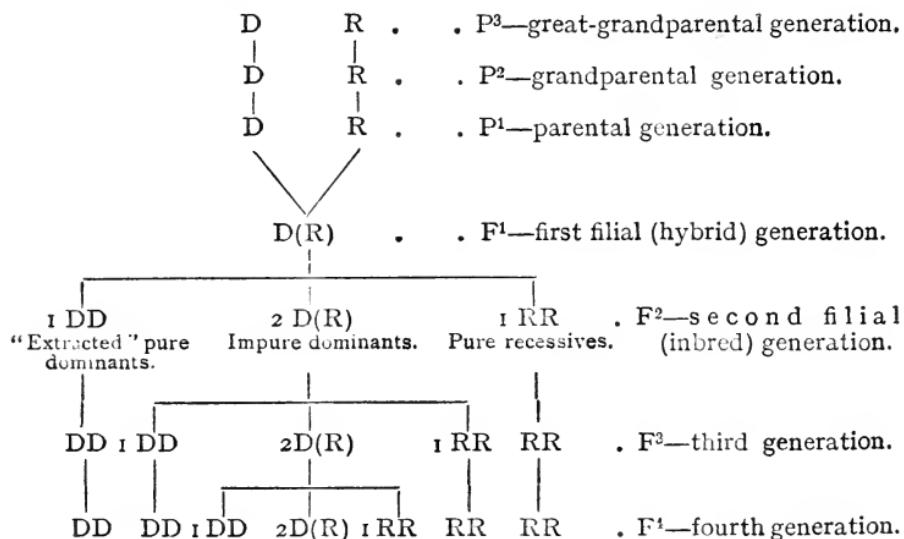
FIG. 48.—MENDELISM.

(*From J. A. Thompson, "Heredity."*)

The same in diagram form :
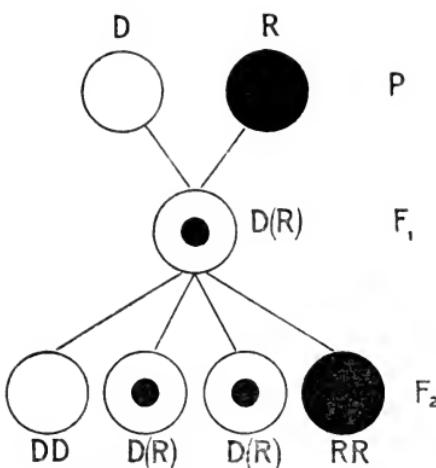
FIG. 49.—MENDELISM.   (After Thomson.)

Here DD stands for pure, or so-called extracted, dominants, RR for pure recessives, and D(R) for impure dominants.

We see, then, that when two distinct varieties are crossed, where one is dominant with regard to a certain character, while the other is recessive, the first hybrid generation (F_1) is an impure dominant. On interbreeding, the next generation (F_2) can be divided into four parts—one pure dominants, two impure dominants, and one pure recessives. The impure dominants split up once more on further breeding into the same proportions, while the pure dominants and recessives each time breed true for all successive generations.

How can these Mendelian phenomena be accounted for ? Mendel himself explained them in a most ingenious, and yet at the same time very simple, manner.

If of the two parent forms under consideration one parent D has the dominant quality d, while the other parent R has the recessive quality r, then the germ-cells of the first parent will all contain the character d, those of the second

parent the character r. Now the fertilized ovum which is derived from the crossing of both parents will combine in itself both qualities, d and r; the hybrid will therefore contain the characters d and r, but as the character r is recessive to d, the hybrid will have the appearance of the dominant parent only.

We call the germ-cells containing the various characters " Gametes," and the product derived from the union of two gametes—$i.e.$, the fertilized ovum—a " Zygote." If the zygote is formed by the union of two gametes having the same character—$i.e.$, both having the d or both having the r character—it is called a " Homozygote " ; if, on the other hand, it contains two gametes of dissimilar characters —$i.e.$, one having the character d, the other the character r— it is called a " Heterozygote." Mendel now assumed that in the gametes of such a heterozygote as our first hybrid a segregation of the two original parent characters d and r takes place in such wise that only one of the characters appears in any given gamete—in our case either d or r, but never both together. Such characters have therefore been called by W. Bateson " allelomorphic characters—$i.e.$, they are a pair of characters which in the constitution of the gametes are alternative to each other "—one may replace the other, but both cannot be contained together within the same gamete. For instance, the green factor cannot be contained in the same gamete together with the yellow, nor is any mixture of them possible. The given hybrid would therefore furnish only two kinds of gametes in equal numbers, one set containing the character d, the other only the character r. If now inbreeding takes place, a union of these two sets of gametes is effected, and three kinds of combinations are possible : a gamete d may unite with another d, a gamete d may unite with one of the type r, or two gametes r may unite in the act of fertilization. The result of these three possibilities can be graphically illustrated in a very lucid manner, according to R. C. Punnett, in the following way : Taking two female

gametes d and two female gametes r, we arrange them in a
square in such wise that the similar gametes are in vertical
lines. We then make another square, which similarly
contains the male gametes, but so arranged that the
similar gametes now lie horizontally next to each other.
If we now superimpose the two squares, we get all the three
possible combinations of male and female gametes in their
numerical proportion.

A

d ♀	r ♀
d ♀	r ♀

B

d ♂	d ♂
r ♂	r ♂

C

| d ♀ | r ♀ |
d ♀	d ♂
d ♀	r ♀
r ♂	r ♂
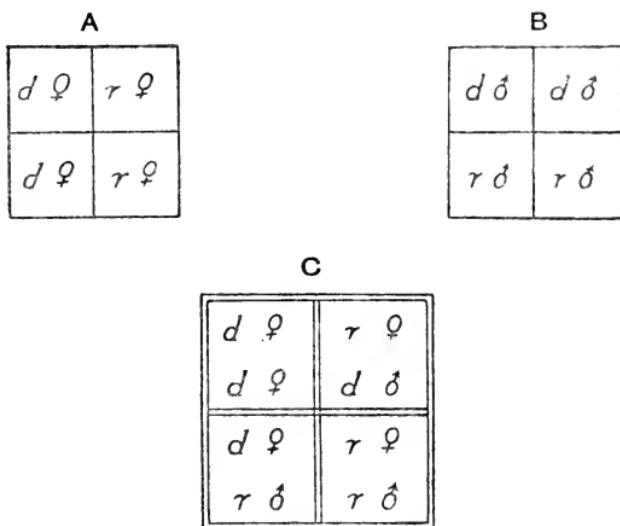
FIG. 50.—PUNNETT'S SQUARE FOR HYBRIDS.

A, female gametes arranged vertically ; B, male gametes arranged
horizontally ; C, male and female gametes superimposed.

Thus we get, on inbreeding of the first hybrid, offsprings
of the following compositions : 1 dd, 1 dr, 1 dr, 1 rr, or
1 dd + 2 dr + 1 rr. (As d is dominant over r, the 2 dr
will in appearance be like d.) We see from this that the
extracted pure dominant of the F_2 generation is a homo-
zygote of the character dd, the extracted recessive a homo-
zygote of the character rr, while the impure dominant is a
heterozygote containing the characters dr. (This is the
reason for writing in the diagram Fig. 48 the extracted

dominants as DD, the impure dominants as DR, and the extracted recessives as RR.) We can now enlarge diagram Fig. 49 by showing the gametes of the different generations and their union. We have the dominant and

recessive parent D and R, which produce by the union of their gametes d and r the hybrid D(R). This hybrid has an equal number of gametes d and gametes r, which, as indicated in the diagram by the arrows, produce one pure dominant, one pure recessive, and two impure dominants.

This theory of the segregation of the unit-characters can be tested by further experiments, and results have been attained verifying with marvellous correctness the
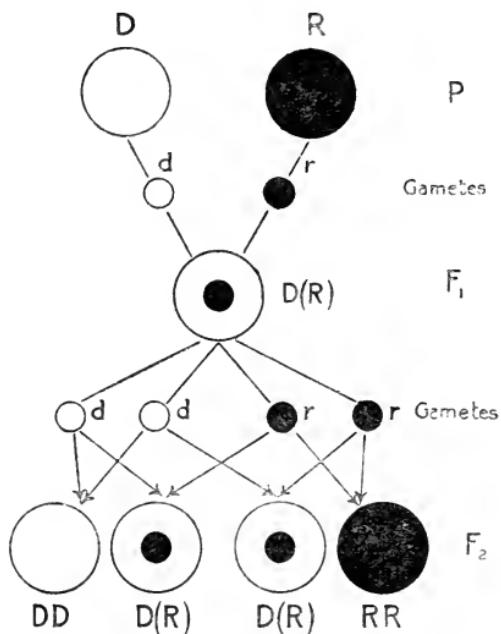
FIG. 51.—GAMETIC SEGREGATION.

(After Thomson.)

supposition made. Assuming that the gametes of the extracted dominant DD contain the character d only, those of the extracted recessives RR the character r, while the gametes of the impure dominants DR contain in equal numbers the character d or character r, then, if crossing takes place, the following will be the result :

DD × RR = all DR, as all gametes d unite each with a gamete r, thus giving DR.

DR × RR = 1 DR + 1 RR, for we have half the number of gametes of DR containing d, half the number

r, while all the gametes of RR contain r.   In the making we get therefore : $d \times r = \text{DR}$ and $r \times r =$ RR, altogether 1 DR + 1 RR.

DR $\times$ DD = 1 DR + 1 DD in the same manner, while

DR $\times$ DR = 1 DD + 2 DR + 1 RR, as already expounded in full.

As we have found the yellow and green colour of the seed to be a pair of allelomorphic characters, so there are in the edible pea other such allelomorphic pairs, behaving in exactly the same manner.   These have been studied and enumerated already by Mendel himself, who has given the following pairs of dominant and recessive characters in the edible pea :

	Dominant.	*Recessive.*
1.	Seeds—yellow	green.
2.	Seeds—round	angular.
3.	Seed-coat—grey (always combined with purple flowers)	white (always combined with white flowers).
4.	Ripe pods—inflated	contracted.
5.	Unripe pods—green	yellow.
6.	Position of flowers—axial	terminal.
7.	Length of stem—tall	dwarfish.

III.—*FURTHER ELABORATIONS OF MENDEL'S LAW.*

While up to now we have given our attention to the behaviour of one pair of allelomorphs only, leading to what are called " Monohybrids," we now direct our examination to cases of Dihybridism, where two pairs of allelomorphs are concerned.   Here each parent has two characteristics, which are dominant or recessive.   How does the Mendelian law work out in these cases ?

If we have two parents of edible peas once more, one with two dominant characteristics—let us say yellow and round seeds—while the other has two recessive characters —green and angular seeds—and we denote the dominant characters yellowness by A and roundness by B, while the

recessive characters are indicated by a (green) and b (angular) respectively, then the two pairs of allelomorphs will be Aa and Bb. The hybrid (F_1) will have the constitution ABab, but will appear like AB, because A and B are dominant over a and b.

We can easily find the proportion of the F_2 generation. Taking the two pairs of allelomorphs, the offspring will be : three dominant to one recessive for each pair of allelomorphs—namely (taking sixteen Individuals for Dihybrids), 12 A to 4 a and 12 B to 4 b. But now a recombination takes place again in the proportion of three dominant to one recessive. Out of the 12 A, 9 A combine with 9 B (dominant), and 3 A with 3 b (recessive). In the same way, out of the 4 a, 3 a combine with 3 B (dominant), and 1 a with 1 b (recessive), so that we get as result : 9 AB + 3 Ab + 3 aB + 1 ab. How can this result be explained in terms of gametes ?

As the two pairs of allelomorphs are Aa and Bb, and as, according to the law of gametic segregation, only *one* unit of each pair of allelomorphs can be contained in the same gamete together with any other unit, we get as gametes of the hybrid the following four possible combinations : AB, Ab, aB, and ab. On further inbreeding of the F_1 generation, all the possibilities of the offspring can once more be graphically represented by means of squares, according to Punnett's method, in the following manner : We take this time sixteen female gametes and sixteen male gametes, four each of the above given constitutions, and arrange them, the female gametes vertically and the male horizontally. Then we superimpose the squares, and find thus all the possible combinations of the F_2 generation.

We find as result the following combinations :

<table>
<tr><td>I. 1 ABAB
2 ABAb
2 ABaB
4 ABab</td><td>} 9 AB..</td><td>II. 1 AbAb
2 Abab</td><td>} 3 Ab..</td><td>IV. 1 abab.</td></tr>
<tr><td></td><td></td><td>III. 1 aBaB
2 aBab</td><td>} 3 aB..</td><td></td></tr>
</table>

Remembering that A and B are dominant over *a* and *b*, the cases under I. will all appear like AB. We get, therefore, nine AB. Those under II. will all be like A*b ;* we

FIG. 52.—PUNNETT'S SQUARE FOR DIHYBRIDS.

A, female gametes arranged vertically ; *B*, male gametes arranged horizontally ; *C*, male and female gametes superimposed.

have, therefore, three A*b*. Those under III. will all be like *a*B ; we have three *a*B. And the case of IV. will appear like *ab*—that is, we have one *ab*.

We get, accordingly, in the second hybrid generation F_2

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four visible types of individuals in the following proportions : $F_2 = 9 AB + 3 Ab + 3 aB + 1 ab$.

It will be seen on closer examination that out of the nine AB, only one is a pure dominant, having the characters ABAB, and therefore breeding true. All the others, though they look like the dominant, contain a recessive character in addition, either *a* or *b* or both together, and are therefore impure dominants. Of the three A*b*, one A*b*A*b* is pure, while the other two have *a* as a recessive. Of the three *a*B, one is a pure *a*B*a*B ; the other two contain *b* as a recessive.
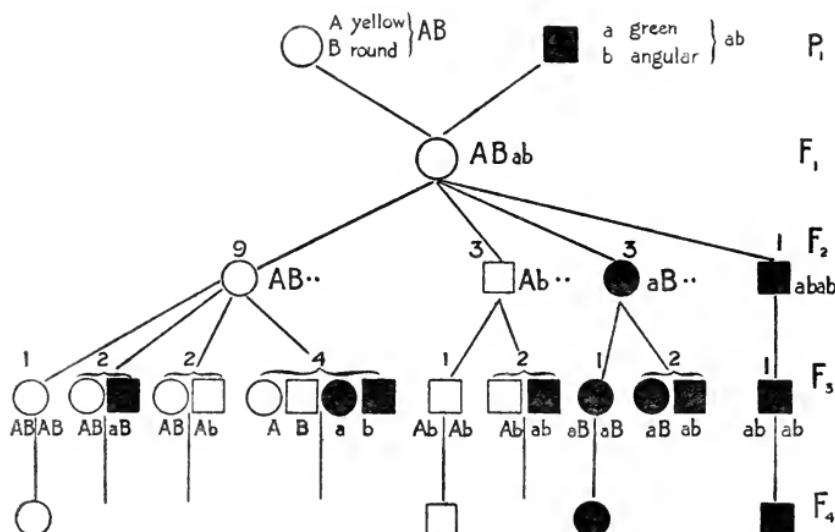
FIG. 53.—DIHYBRIDISM. (After Lotsy.)

Lastly, *abab* is a pure recessive. It follows from this that, on further inbreeding of the above four types (each separately), we get in the F_3 generation one true-breeding line from each—viz., ABAB, *a*B*a*B, A*b*A*b*, and *abab*—while all the others, being impure strains, will, on further breeding, show the phenomenon of segregation.

One more most important result can be seen to flow from this fact. We started with two pure types—viz. AB, yellow and round, and *ab*, green and angular. Now

we have two new true-breeding, pure types—A*b*, yellow and angular, and *a*B, green and round. In other words, we are able, on the Mendelian principle, to create in two successive generations new types breeding true indefinitely. The diagram from J. P. Lotsy on p. 130 will make the descent of all the types clear at a glance.

With three allelomorphs, A*a*, B*b*, C*c*, we get a hybrid of the constitution ABC*abc*. The F_2 offspring will give eight visible types, in the following proportion :

$$F_2 = 27 \text{ ABC} + 9 \text{ } a\text{BC} + 9 \text{ A}b\text{C} + 9 \text{ AB}c + 3 \text{ A}bc + 3 \text{ } a\text{B}c + 3ab\text{C} + 1 \text{ } abc,$$

and so on with more allelomorphs.

IV.—COMPLICATIONS.

Not all cases of Mendelian inheritance work out so simply as those given in the previous account. There are phenomena which at first sight appear rather complicated, and need some further elaborations in order to be made amenable to Mendel's law.

In the first place, the dominance of one of the characters may be incomplete. Thus, when white Leghorn poultry is crossed with brown, the hybrid is not completely white, as would be expected according to Mendel's law, but it has invariably a few dark splashes. In other respects the hybrid behaves in the regular manner, and, on inter-breeding, splits up into one-quarter white birds, one-quarter brown ones, and two-quarters white birds with " ticks " of colour.

A still more interesting case is that of the Andalusian fowl. Here the hybrid differs completely from either the dominant or the recessive parent. It is blue, while the dominant parent is black, the recessive being white with black splashes. On inbreeding, this hybrid yields, in the ordinary Mendelian manner, one-quarter black birds, one-quarter " splashed whites," and two-quarters blues. If we cross the blacks with the whites, we get all the off-spring blue, while the blue always show on inbreeding

50 per cent. " wasters." Thus was explained the puzzling phenomenon, which could not be solved for a long time, that, while the crossing of two blue birds only gives 50 per cent. of blues, the crossing of a black with a white bird produces a progeny all of which are blue. The explanation is that the black and white are the pure breeds, while the blue is a Mendelian hybrid. The following diagram will make this clear :
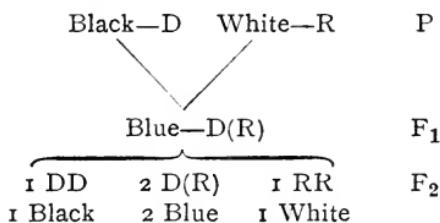
FIG. 54.—ANDALUSIAN FOWLS. (After Bateson.)

(a) COMPOUND CHARACTERS.

So far, when we had to deal with two pairs of allelomorphs, the units of each allelomorphic pair expressed a character of the organism distinct from the character expressed by the second allelomorphic pair. We had, *e.g.*, the allelomorphs yellow-green, as affecting the colour of a part, distinct from the allelomorphs round-angular, as affecting the form of that part, the one effect being nowise dependent on the other. We now come to cases where the units belonging to different allelomorphic pairs do react on each other, thereby producing new forms. Such allelomorphs have been called " compound allelomorphs." The character resulting from them are compound characters —*i.e.*, they are single characters produced by the concurrence of more than one allelomorphic factor.

A case in point is that of crosses between red-flowered and cream-flowered varieties of sweet-peas or stocks. By crossing the red variety with a cream-coloured variety we get a hybrid which, being a dihybrid, produces, on

inbreeding, four different types of coloured flowers in the offspring : the dominant red type, the recessive cream type, and two new types—one having a red-cream, the other a white colour of the flower.

The explanation is as follows : The red colour of the flower is due to red sap, which is dominant to colourless sap. The cream colour, on the other hand, is due to yellow corpuscles, and is recessive to colourless corpuscles. We get, accordingly, after W. Bateson, the following scheme, which explains itself :

Red Variety × *Cream Variety.*   P

Two allelomorphic pairs :
    1. Red Sap—D   2. Colourless Corpuscles—D
      Colourless Sap—R   Yellow Corpuscles—R

$$\left.\begin{array}{c}\text{Red Sap}\\+\\\text{Colourless Corpuscles}\end{array}\right\} = Red \qquad F_1$$

Red Sap : Colourless Corpuscles	Red Sap : Yellow Corpuscles	Colourless Sap : Colourless Corpuscles	Colourless Sap : Yellow Corpuscles

Appearance :
| 9 *Red* | 3 *Red-Cream* | 3 *White* | 1 *Cream* | F_2 |
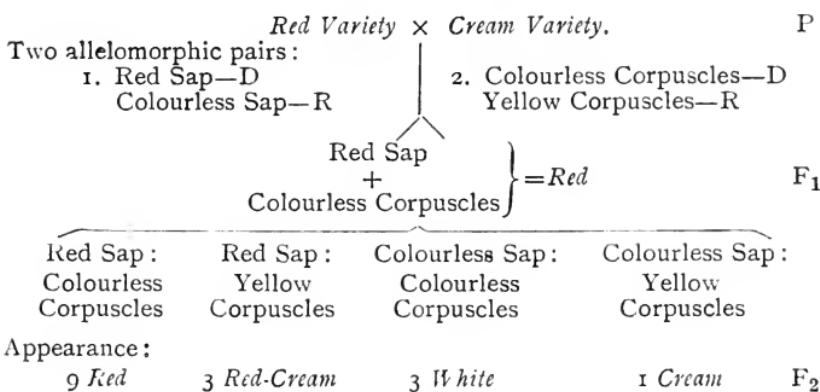
FIG. 55.—COLOURED FLOWERS.   (After Bateson.)

A similar case is presented by the combs of fowls. We can distinguish four kinds of combs : (1) A large serrated single comb, as in the Leghorn and Andalusian breed ; (2) a flattened papillated " rose " comb, as in the Wyandottes and White Dorking ; (3) a threefold-ridged comb, the " pea " comb, in the Indian game fowl ; and, lastly (4) the corrugated " walnut " comb of the Malay fowl.

Both rose and pea comb are dominant to the single comb ; while the cross between the rose *and* pea comb gives a walnut comb, which on further inbreeding produces the usual four Mendelian types, in the proportion of nine walnut, three rose, three pea, and one single.

The explanation is similar to that given in the previous

instance. If we denote the dominant rose quality by R, the dominant pea quality by P, and further, the absence of the rose quality by r and the absence of the pea quality
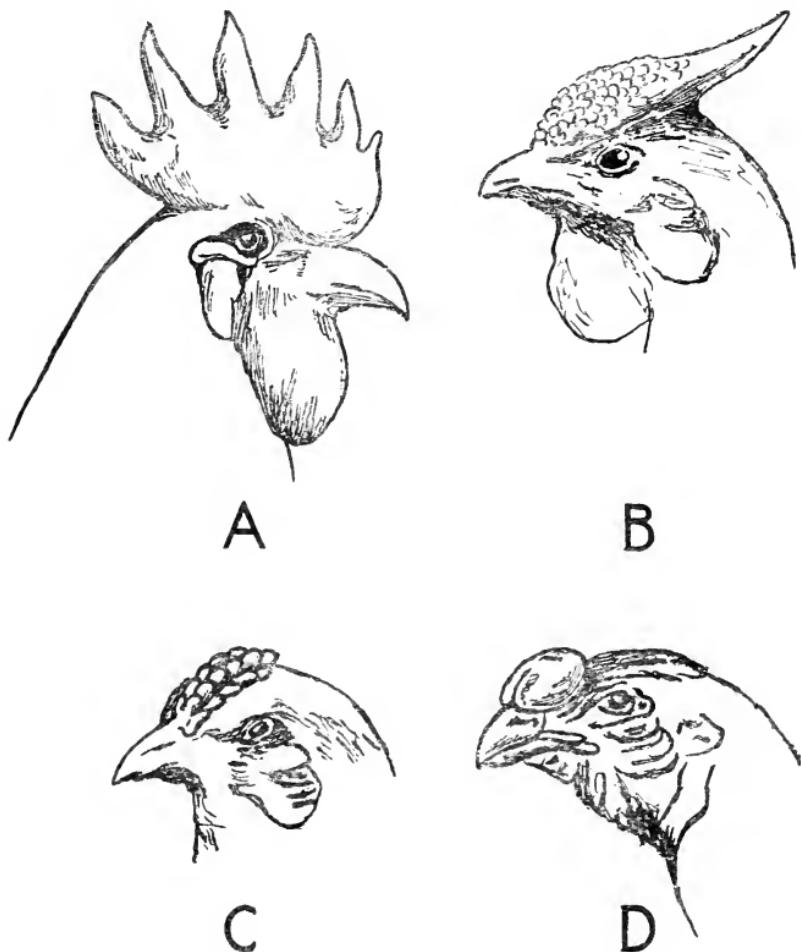
Fig. 56.—Combs of Fowls. (After Thomson and Weir.)

A, single serrated comb; B, rose comb; C, pea comb; D, walnut comb.

by p, then r as well as p will denote a single comb, both r and p being recessive to either rose comb or pea comb. $R \times P$ gives a walnut; $r \times p$ gives, as R and P are absent,

a single comb. The difference from the previous case lies
in the fact that both recessive characters, r as well as p,
are identical, representing the single comb. (It will be
noted also that, whilst up to now in the production of a
dihybrid one parent had both dominant, the other both
recessive, characters, here each parent has one dominant
and one recessive character.) We get, accordingly, the
following scheme, which explains all the possible com-
binations :

<div style="text-align:center">Rose Variety × Pea Variety.   P</div>

Two allelomorphic pairs :
  1. Rose—R   2. Pea—P
     Absence of Rose—r (Single)   Absence of Pea—p (Single)

$$\left.\begin{array}{c}\text{Rose}\\+\\\text{Pea}\end{array}\right\} = Walnut \qquad \mathrm{F_1}$$

9 RP	+	3 Rp	+	3 rP	+	1 rp	
9 *Walnut*		3 *Rose*		3 *Pea*		1 *Single*	$\mathrm{F_2}$
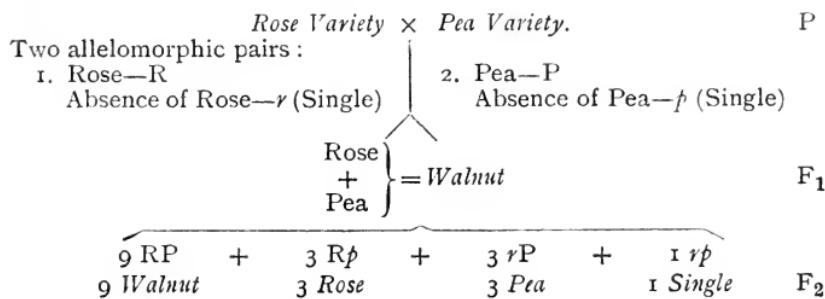
<div style="text-align:center">FIG. 57.—COMBS OF FOWLS. (After Bateson.)</div>

We have thus in both cases just described definite
characters—*i.e.*, the various colours of flowers and the
different shapes of the combs respectively produced " by
the mutual interaction of factors belonging to distinct
allelomorphic systems."

One more point coming out in the consideration of the
phenomena just described needs mentioning here. We
have taken the absence of the dominant factor as the
recessive character, and found that on that hypothesis
we could work out satisfactorily on Mendelian lines the
combinations given. Whatever the absence of a character
may actually mean as a characteristic of the organism
itself, this assumption is in the present stage of our know-
ledge the only means of dealing with such cases.

(b) Masked Characters.

There are other cases, now to be discussed, which present still more complications. If grey rabbits are crossed with albinos, the F_1 generation are all grey. On interbreeding, we get an F_2 generation :

$$F_2 = 9 \text{ grey} + 3 \text{ black} + 4 \text{ albinos.}$$

This proportion differs from the usual Mendelian proportion, which is $9 + 3 + 3 + 1$. To understand the case, we once more assume two pairs of allelomorphs—(1) Pigmentation A and Albinism a, and (2) Greyness B and Blackness b, where A and B are dominants, a and b recessives.
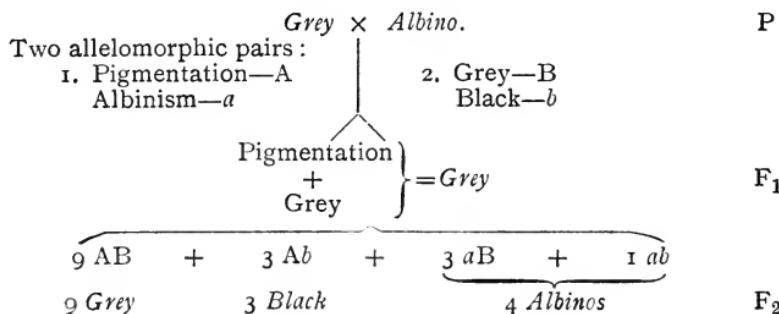
FIG. 58.—RABBITS. (After Bateson.)

The explanation of the case lies in the fact that neither the grey factor (B) nor the black factor (b) can assert itself, unless the pigmentation factor (A) is also present. We get $9 \text{ AB} + 3 \text{ A}b + 3 \text{ }a\text{B} + 1 \text{ }ab$; but aB cannot be distinguished from ab, both types appearing as albinos, because the factor A is absent from both. Indeed, the real underlying character of the aB's is masked by Albinism. We therefore get, instead of the usual proportion of $9 + 3 + 3 + 1$, only $9 + 3 + 4$, the last two types, $3 \text{ }a\text{B} + 1 \text{ }ab$, giving four albinos

The four albinos are not all of the same constitution, as will be seen at once if we set out the case in a Punnett's square, taking the same two pairs of allelomorphs, A*a* and B*b* :

FIG. 59.—PUNNETT'S SQUARE FOR RABBITS.

The shaded squares denote the greys, the black ones the blacks, and the white ones the albinos. It will be seen from the above diagram that there are three different kinds of albinos—viz., one *a*B*a*B, two *a*B*ab,* and one *abab*. On crossing each type with a black, *e.g.*, the difference of their constitution becomes at once apparent, for we get :

$$aBaB \times Ab.. = AB.. \text{ (all grey).}$$
$$aBab \times Ab.. = \text{I } AB.. \text{ (grey)} + \text{I } Ab.. \text{ (black).}$$
$$abab \times Ab.. = Ab.. \text{ (all black).}$$

The next case, that of the sweet-pea, is still somewhat more involved. Here we have two white peas giving, on crossing, a purple dihybrid. This dihybrid, on inbreeding, produces a progeny of 9 purples + 7 whites. The explanation is similar to that of the previous case ; but while in the last case of the rabbits the presence of one factor only, that of pigmentation, was essential for the reproduction of coloured rabbits, here two factors are

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essential, each white bringing in a separate colour factor. If we denote the two colour-producing factors by A and B (both being dominant), and the absence of the colour-producing factors by *a* and *b* (being recessive), then we get the following scheme :

$$\begin{matrix} \textit{White (A Variety)} & \times & \textit{White (B Variety).} & & \text{P} \end{matrix}$$

Two allelomorphic pairs :

1. Colour factor—A   2. Colour factor—B
   Absence of Colour—*a*   Absence of Colour—*b*

$$\left. \begin{matrix} \text{Colour factor A} \\ + \\ \text{Colour factor B} \end{matrix} \right\} = \textit{Purple} \qquad \text{F}_1$$

9 AB	+	3 A*b*	+	3 *a*B	+	1 *ab*	
9 *Purple*				7 *White*			F$_2$
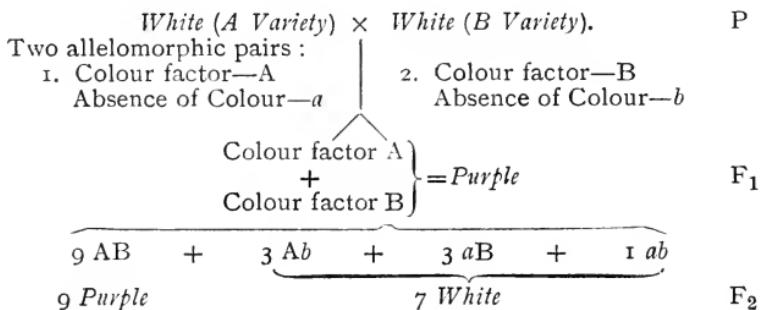
Fig. 60.—Sweet-Pea. (After Bateson.)

AB, containing both colour factors, is purple ; but A*b*, *a*B, and *ab* are all white, because they either contain only one colour factor (A or B) or none.

Here once more, the proportion 9 : 7 only masks the Mendelian proportion of $9 + 3 + 3 + 1$, the latter three types being identical in appearance, though in reality of a different constitution.

The two cases last discussed throw incidentally some light on the phenomenon of Reversion. The white colour of the sweet-pea is a new character, which, on intercrossing, reverts to the ancestral purple flower. Similarly, the cross of a black and albino rabbit yields the wild grey form. Evidently reversion in both cases is due " to the meeting of factors belonging to distinct allelomorphic pairs," which in the new forms have become separated. On crossing the new forms, these necessary factors once more reunite, producing the old racial type.

V.—*RESULTS.*

The discoveries of Mendelian phenomena have opened up new vistas to our inquiries on Heredity, which have been groping so long in the dark. Not only scientific theories of the greatest consequence flow from the facts ascertained, but also practical results of far-reaching importance. Not unfittingly has R. C. Punnett compared the position we have now attained in regard to the knowledge of Inheritance with the discovery of the atomic theory in Chemistry by Dalton. We are at last on the first rung of the ladder leading to an exact knowledge of the phenomena of heredity.

It has become evident that the individual is an entity made up of hereditary unit-characters. The aggregate of such units forms the individual. During the process of inheritance the units segregate, and by recombination form new individualities. And this is the most important result accruing to the art of the practical breeder. He can now, by judicious crossing, produce new strains—not blindly, as before, but with an exact knowledge of what he wants and what he can achieve. We have seen, for instance, that by crossing two varieties a dihybrid can be produced which in the next generation reproduces, not only the two original parent forms, but also, by reuniting the parental characters in different combinations, two novel forms. We have further seen that within this number of individuals of the F_2 generation there are four true breeding types which, by careful separate breeding can be recognized and fixed in the next generation. It is clearly shown that, if this is done scientifically on Mendelian principles, only two generations of breeding are required to produce a new and stable form. Furthermore, it has become clear that there is no fear of the new forms being swamped by inter-crossing, as new forms and old ones breed out separately, and breed true.

The theory of Darwin that evolution takes place by small,

gradual, continuous steps has thus been somewhat shaken, while, on the other hand, De Vries's contention that larger and sudden variations, called by him "Mutations," form the material for Natural Selection, finds support in Mendelism.

The Mendelian law of inheritance has been verified in a host of plants and animals ; but it must be well understood that it applies in each case only to certain characteristics of the organism, which form allelomorphic pairs, of which one unit is dominant, the other recessive. With regard to cultivated plants and domesticated animals, a new era has dawned. Man is now able to unite given desirable qualities in new favourable combinations. More than that, undesirable characters can be bred out once for all by rejecting those individuals which have the undesirable combination, without fear of losing the desirable qualities, for the breeder can, in a Mendelian case, ascertain with absolute certainty the underlying constitution of each given individual.

As for man, little progress has so far been made with the application of Mendel's law. Some pathological characteristics have been found to show Mendelian phenomena. In addition, eye colour in man "mendelizes" (a short convenient term for denoting breeding according to Mendel's law). But we are only on the threshold of our knowledge. More, much more, is to come yet, and the beginning made augurs well for the future.

Before finally leaving this subject we must slightly touch on the relationship between the phenomena of Mendelian crosses and those of Hybridism as given by Weismann. Both Weismann and Mendel assume units of characters (Weismann's Determinants), which in their totality make up the given organism. But while in Mendelian cases, to use Professor Thomson's words, " the unit-characters are stable, and will not blend with other contrasted analogous units, in other cases the unit-characters are not so 'exclusive,' but may combine with

analogous unit-characters to form a blend or a particulate mosaic." We must therefore distinguish between Mendelian hybrids, which do not blend, but breed out the various forms in ascertained proportions, and those results of hybridization usually described as prepotent, blended, or particulate inheritance. Most probably there are, as Professor Thomson indicates, " several formulæ of inheritance, each applicable to particular sets of cases—*e.g.*, to cases where blending does occur, and to cases where it never occurs." For the present a higher unification of both sets of phenomena has not been attained.

CHAPTER IX

BIOMETRICS

I.—INTRODUCTION.

THERE seems at first nothing so futile as seeking for any definite order in the daily occurrences of life, be it births, marriages, deaths, or the hundred and one other events that make up the sum total of our social existence. Chance and chaos appear here to reign supreme. And yet, though we may be unable to tell who is going to be born, who to be married, or who is destined to die in any given year, it is a well-known fact that the proportion of births, marriages, and deaths to the total population can be expressed by a definite percentage for any given period, and that, assuming the same conditions, this ratio varies comparatively little from year to year. Prediction is possible—if not for the individual case, yet for the mass. The science of statistics forms a recognized and most important part of our study of social phenomena.

Biometrics occupies itself, as its name signifies, with the measurement of the phenomena of life. It applies to biology the mathematical methods of statistics. The first to treat biological problems from this point of view was the famous Belgian astronomer and statistician Quetelet, who, in his *Letters on the Theory of Probability* (1846), demonstrated that variation takes place, according to the well-known Laws of Probability. But to Francis Galton belongs the honour of having been the pioneer of this school of biology. It was he who in various papers,

and especially in his *Natural Inheritance* (1889), laid the foundation for all modern researches of Biometrics. His foremost pupil is Karl Pearson, who has made this subject especially his own, and to whom we owe the name of this science, Biometrics.

II.—*VARIABILITY AND NORMAL FREQUENCY CURVE.*

It is a well-known fact that Darwin based his theory of Natural Selection on the existence of individual differences which occur as a regular phenomenon among plants and animals of any species. These variations, as they are called, form, according to him, the material of all organic evolution, which takes place by small insignificant steps, accumulating in successive generations, and thus leading to a gradual transformation of species. While the battle had to be won for the principle of evolution, little attention was paid to the basic material of evolution, and it is only lately that variations have been investigated in a methodical manner, chiefly by W. Bateson and De Vries. They discovered that, in addition to the small individual differences which occur between all members of any given species, there are cases where the differences are larger, more abrupt, and distinct. While the former variations are called normal, fluctuating, or continuous, the latter are called abnormal, definite, and discontinuous. For instance, the normal differences in the stature of man are slight, and range themselves easily into a graduated scale from very small to very great heights ; on the other hand, the number of petals in certain flowers (ox-eye daisy, primrose, etc.) may vary very considerably, each additional petal meaning a distinct and sudden variation of the flower in that direction. De Vries has called the discontinuous variations " Mutations," and maintains that Natural Selection takes place only by their means, new and distinct varieties being established in one bound, while the individual variations are due to differences of nourishment, etc., and are ineffective

as regards Natural Selection. We may here say that Natural Selection by means of discontinuous variations has been accepted as an established fact, and Mendelism, which shows the possibility of a recombination of parental factors in a new form without transitional stages, has lent much support to the Mutation theory of De Vries. To what extent, and whether individual continuous variations are a source of progressive evolution, is at present a moot point.

But our knowledge of variation has progressed further. We are able to tell not only that organisms vary and how they vary, but to what degree they vary ; in other words, we have learnt to measure variability.

Let us take, to follow R. H. Lock's statement of the subject, measurements of any character—*e.g.*, the strength of pull of certain men—as recorded by Galton in his *Natural Inheritance* in the following table :

Strength of Pull.	Number of Cases observed.	Percentages.	
		Number of Cases observed.	Sums from beginning.
Under 50 lbs.	10	2	2
„ 60 „	42	8	10
„ 70 „	140	27	37
„ 80 „	168	33	70
„ 90 „	113	21	91
„ 100 „	22	4	95
Above 100 „	24	5	100
Total	519	100	

FIG. 61.—TABLE OF STRENGTH OF PULL. (After Galton.)

(From R. H. Lock, " Recent Progress in the Study of Variation, Heredity, and Evolution.")

We can arrange these measurements diagrammatically in the following figure, where the horizontal scale gives us the number of pounds pulled, and the vertical scale the

number of men in percentages who exerted a given pull
(equal distances being marked off on the base line for equal
numbers of pounds, and in the same way equal distances of
the vertical line for each percentage). For instance, 2 per
cent. show a strength of pull of under 50 pounds, 8 per
cent. of between 50 and 60 pounds, 27 per cent. of between
60 and 70 pounds, etc. If we connect the tops of these
columns, we get a broken line representing the curve of
variation for the given measurements of strength of pull.
We see at once that the number of persons showing the
two extreme amounts of strength, the very weak and the
very strong men, is smaller than of those exhibiting a
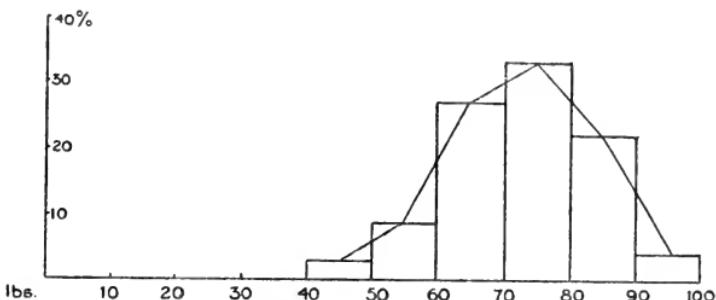
Fig. 62.—Diagram of Strength of Pull. (After Galton.)

medium strength of pull, and that the curve gradually
slopes down towards both ends.

If we have more exact measurements from a greater
number of people, the curve becomes a more regular flowing
one, as in Fig. 63, where variations in stature are repre-
sented, the result of 4,426 measurements of members of
Cambridge University of British extraction, recorded by
the Cambridge Anthropological Society. The base line
gives the stature in inches, the vertical line the number of
individuals exhibiting the different heights of stature.
Here the continuous line going through the points of
measurements plotted out in the diagram represents very
nearly a curve, which is identical with what is called in

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mathematics the " Normal Curve of Frequency of Error," or, shortly, the " Normal Frequency Curve."
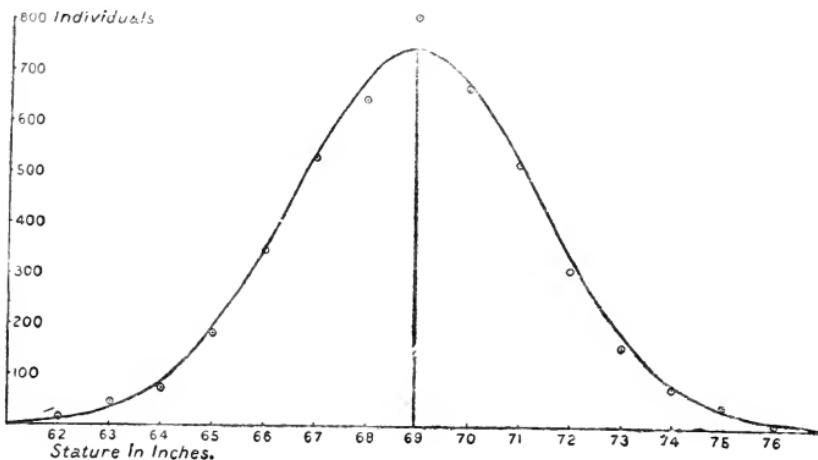
FIG. 63.—CURVE OF STATURE.

(From R. H. Lock, " Recent Progress in the Study of Variation, Heredity, and Evolution.")

In order to comprehend what the Normal Frequency Curve stands for, we must enter somewhat into the field of the mathematical theory of probability.* If we toss up two similar coins simultaneously there are three possibilities : We may get head-head (H-H), head-tail (H-T), or tail-tail (T-T). When tossing up the coins a very great number of times, we find that, according to the Law of Probability, we get head-tail twice as often as either head-head or tail-tail. We get, in fact :

$$\text{1 H-H} + \text{2 H-T} + \text{1 T-T.}$$

(This is due to the fact that in tossing up the two coins many times—*e.g.*, fifty times—we throw up

---

* We can give only the very briefest account of this subject, which is mathematical and very abstract, and shall also in the following pages state only the most essential facts of Biometrics, seeing that this science involves the application of advanced mathematics.

each head fifty times and also each tail fifty times. To-
gether we have 100 throws of heads and 100 throws of
tails. To get head-head or tail-tail we have the choice
from 100 throws each time, while to get head-tail we have
the choice from 100 throws of heads plus 100 throws of
tails—*i.e.*, from 200 throws. Therefore the chance of
getting head-tail is double as great as of getting either
head-head or tail-tail.) Similarly, if we toss up three coins
we get the following possibilities :

$$1 \text{ H-H-H} + 3 \text{ H-H-T} + 3 \text{ H-T-T} + 1 \text{ T-T-T,}$$

and so on with more coins. For ten coins simultaneously
tossed up we get the following series of possibilities
and their relative probabilities.

Heads.	Tails.	Relative Probability.
10	0	1
9	1	10
8	2	45
7	3	120
6	4	210
5	5	252
4	6	210
3	7	120
2	8	45
1	9	10
0	10	1

FIG. 64.—TABLE OF TEN TOSSED COINS.

(*From R. H. Lock, " Recent Progress in the Study of Variation,
Heredity, and Evolution."*)

The same series plotted in a curve gives us Fig. 65.

We see here once more that the extreme possibilities are
rare, while the medium possibility (5 H – 5 T) is the most
frequent one, the other possibilities gradually becoming
less towards both ends of the curve. The probability
curve of ten coins is still rather angular, but if we construct
the curve for the relative probabilities of a great number
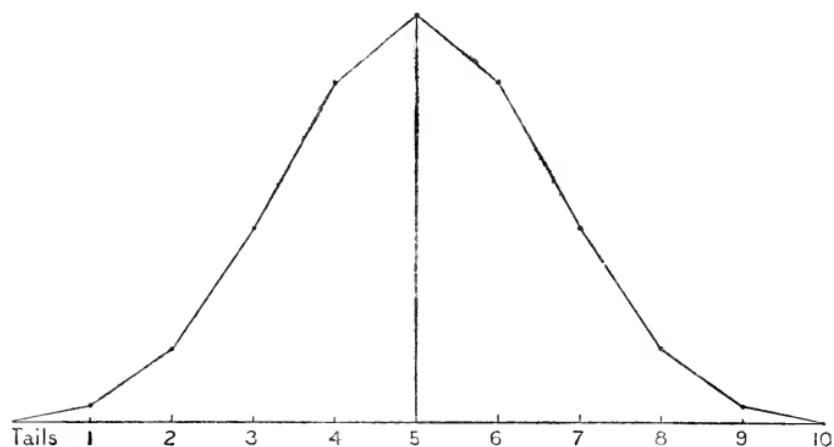
FIG. 65.—CURVE OF TEN TOSSED COINS.

(From R. H. Lock, " Recent Progress in the Study of Variation, Heredity, and Evolution.")
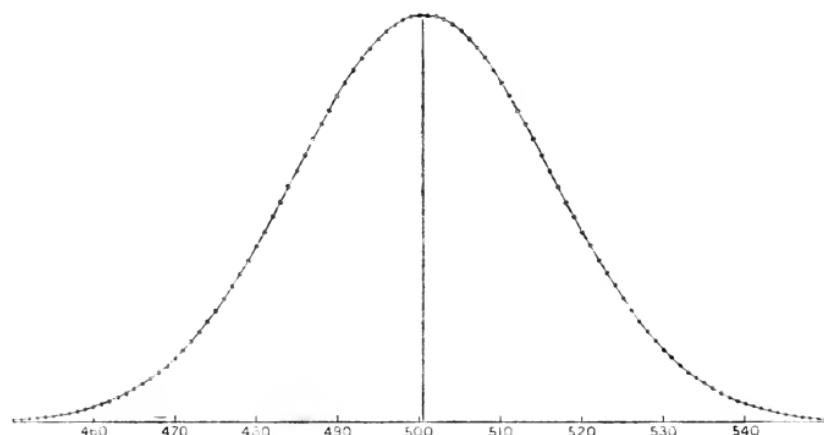
FIG. 66.—CURVE OF PROBABILITY.

From R. H. Lock, " Recent Progress in the Study of Variation, Heredity, and Evolution.")

of coins—*e.g.*, 999—we approach more and more to the mathematical Curve of Probability as given in Fig. 66.

We find, in other words, that the Curve of Variability

and that of Probability—*i.e.*, the Normal Frequency Curve —are identical.

This is a very important discovery. It enables us to deal with variations in a scientific manner, and we are now in a position to define variability in exact mathematical terms. It is necessary to point out that the normal frequency curves for different sets of conditions have different shapes, and that in the same way the general contours of the curves of variability are changeable in accordance with the range of variations represented by the curves.
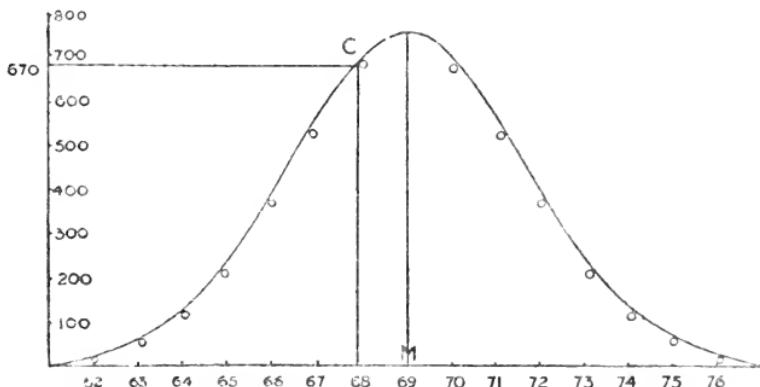
FIG. 67.—NORMAL FREQUENCY CURVE.   (After Lock.)

Now, such a normal curve gives us a large amount of information about the variations plotted. We not only know the measurements and numbers of the variations actually plotted in the curve, but we can also determine the number of individuals having any given measurement, and, on the other hand, the measurement of any given number of individuals. In order to find—*e.g.*, in Fig. 67, which is identical with Fig. 63—the number of individuals that have a height of 68 inches, we erect a vertical line on the measurement 68 inches, indicated on the base line, which cuts the curve at C. If we now draw through C a line parallel to the base line, where this cuts the vertical

line we get the number of individuals having the stature of 68 inches—*i.e.*, about 670. *Vice versa*, if we draw a line parallel to the base line from this same point, it will cut the curve at C. A perpendicular from C on to the base line will go through the point marked 68 inches, indicating thereby that 670 individuals out of the whole number possess that height.

But the Normal Frequency Curve gives us more information still. The line drawn vertically from the highest point of the curve on to the base line gives us the " Mode "
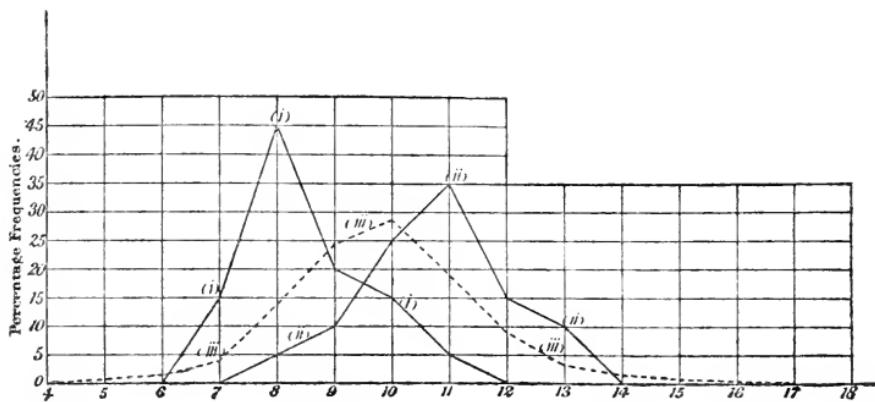
FIG. 68.--CURVES OF POPPIES.

(From Karl Pearson, " The Grammar of Science.")

of the variations—*i.e.*, that variation which is possessed by the greatest number of individuals in Fig. 67 represented by the vertical M. The line which divides into equal halves the area enclosed by the curve is called the " Median," and the variation indicated at the foot of the median on the base line gives us the " Mean" or "Average " of all the variations from which the curve is constructed— —*i.e.*, half the number of individuals measured have more and half the number have less than the mean variation.

In Fig. 68 are represented, according to Professor Karl Pearson, the curves for the number of stigmatic bands

(the dark rays on top of the seed-capsule) in three groups
of poppies—in Nos. I. and II. for two wild poppies, in
No. III. for a greater number of poppies forming a local
race. The numbers of stigmatic bands are indicated on
the base line. We have the following modes and means of
the three curves respectively :

			Mode.		Mean.
No. I.	..	..	8	..	8·50
,, II.	..	..	11	..	10·75
,, III.	..	..	10	..	9·84

We see that the race has a mode different from either of
the individual poppies, and also a different mean.

In a symmetrical curve—and we shall in the following
deal only with symmetrical curves—the mode and mean
fall together : in curve III. this is nearly so, there being a
very slight difference between the mode and the mean.
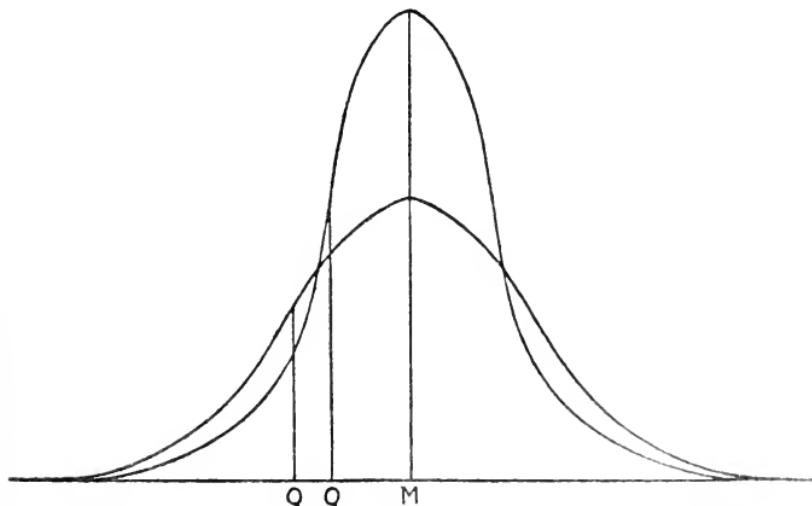
FIG. 69.—CURVES OF PROBABILITY. (After Lotsy.)

But all this is not yet sufficient. What we want is to be
able to compare the variability of one set of varying
characters with another set. In other words, we have to

compare the different curves of variability with each other. Now, given the median in a symmetrical curve, we can find the measure of variability in any given curve. In comparing different curves we find that they differ in their steepness—that is, some are flatter with the base more spread out, others steeper (see Fig. 69). Assuming both curves to stand for the same number of observations (which implies that both curves have the same area), the flatter curve with the greater base indicates greater variability, the steeper curve less variability, of the characters plotted. We have therefore in the steepness of the curve a common measure of the variability of both
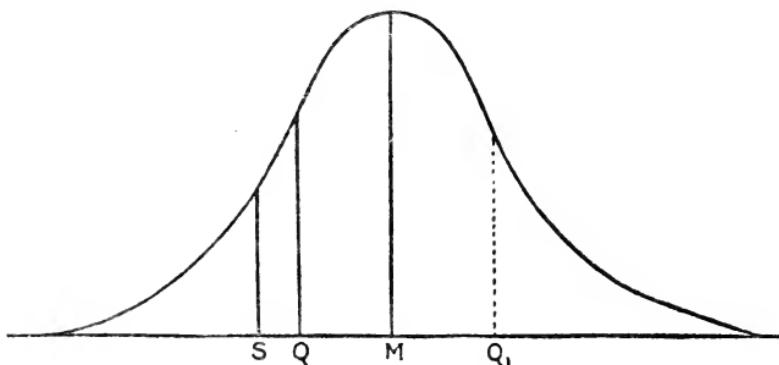
FIG. 70.—CURVE OF PROBABILITY, WITH MEDIAN (*M*), QUARTILE (*Q*), AND STANDARD DERIVATION (*S*). (After Vernon.)

curves by determining the degree of spread of each curve. This can be done in various ways, which it would be too difficult here to propound in detail. We shall fully explain only one method, that of determining what is called the " Quartile " of the Curve.

The median, we have said, divides the area of the curve into two equal halves ; now the quartile (Q) is a vertical line on each side of the median, which divides each half-area of the curve into two equal quarters. The distance of this quartile from the median (MQ or MQ_1) will be greater in the flatter curve (see Fig. 69), and thus this length MQ

(or MQ_1) gives us a convenient measure of variability of the material in question. As curves drawn from an actual series of observations are never absolutely symmetrical, the mean of MQ and MQ_1 is taken, so that

$$q = \frac{MQ + MQ_1}{2}.$$

This q is called the " Probable Error " of variation, because it is practically identical with what the mathematicians call the " Probable Error of the Normal Frequency Curve." This, then, gives us the " measure of variability." In Fig. 68 we see that the variability of the poppy race (III.) is greater than the variability of either of the individual poppies.

In practice it is difficult to determine mathematically the quartile of a given curve. But q can easily be determined in another way by calculation. Taking Galton's table of the strength of pull, we find in the fourth column that 37 per cent. of all the men have a strength of pull under 70 pounds, and 70 per cent. of them one under 80 pounds. We can calculate from this that 50 per cent. have a pull of under 74 pounds, or, in other words, the mean of the whole group M equals 74 pounds. Similarly, it can be calculated that 25 per cent. would have a pull under 66 pounds, and 75 per cent. one of under 82 pounds—*i.e.*, Q = 66 pounds, Q_1 = 82 pounds. We get therefore :

$$\begin{array}{l} MQ = 74 - 66 = 8 \text{ pounds} \\ MQ_1 = 82 - 74 = 8 \quad ,, \end{array} \quad , \quad q = \frac{MQ + MQ_1}{2} = \frac{8 + 8}{2} = 8 \text{ pounds}$$

The Probable Error is therefore $q = 8$ pounds.

If we compare this 8 pounds with the average strength of pull, which is 74 pounds, we find it is 10·8 per cent. of that amount, and we get the " Relative Probable Error " as 10·8 per cent. This, then, is the " Index of Variability " we searched for. The greater the index the greater the variability of the given character, and *vice versa*.

Some examples of the Index of Variability, according to Galton, are:

				Man.		*Woman.*
				Per Cent.		Per Cent.
Stature	..	..	..	2·50	..	2·52
Span of arms	..	..	2·92		..	2·92
Weight	..	..	..	6·89	..	8·89

We see that weight is twice as variable as either stature or span of arm, and is more variable in woman than in man.

There are other methods of determining the variability of a characteristic, which we cannot deal with here in detail. One largely used by Karl Pearson is what has been called the " Standard Deviation." Under " Deviation " we understand the amount by which any individual differs in a given character from the " type." The type may be measured by the mode or the mean; usually we take deviations from the mean. For instance, if we have the following series, where the frequencies represent the number of leaves of a beech-tree showing a given number of veins:

Number of veins ..	15	16	17	18	19	20	$\Big\{$ Mean number of veins, 17·5 = type,
Frequencies ..	1	4	7	9	4	1	$\Big\{$ Total number of individuals, 26,

we get the deviation of each individual group by finding the difference between its actual number of veins and the mean number of veins of the whole series. The deviation for the first group of individuals as given above is $17·5 - 15 = 2·5$, that of the second $17·5 - 16 = 1·5$, etc. We find the standard deviation by multiplying the frequency of each individual group by the square of its deviation from the mean, adding all these products together, and dividing the whole by the total number of individuals. The square root of this total gives the standard deviation, or σ. In the above instance we get

$$\sigma = \sqrt{\frac{1 \times (2·5)^2 + 4 \times (1·5)^2 + 7 \times (·5)^2 + 9 \times (·5)^2 + 4 \times (1·5)^2 + 1 \times (2·5)^2}{26}} = 1·15.$$

This σ is not the same value as q, but one can be converted into the other, for $\sigma = q \div 0.6745$.

There are other variations which cannot be expressed in a single flowing curve, but which give broken curves with two or more humps. Such curves cannot be resolved into a single mathematical formula.

By some it has even been doubted whether discontinuous variations, as exemplified by eye-colour, etc., are legitimate material for the biometrician, as the Law of Probability applies only to cases where a great number of small concurrent factors is involved.

III.—CORRELATION AND REGRESSION.

So far we have dealt with variations of a single character for a given series of individuals, and found a measure of its variability. But the organism is a whole ; its parts are to a great extent interdependent, characters in one part of the body being often closely related to certain other characteristics in a different part of the body. Variations in any such character cause simultaneous variations to a greater or lesser extent in the correlated character. This phenomenon of " Correlated Variation " is a very common one, and has been made familiar by Darwin, who described many curious cases. Thus, he mentions that white cats with blue eyes are generally deaf ; long-haired and coarse-haired animals are apt to have long and many horns ; pigeons with feathered feet have skin between their outer toes, etc. A relation is said to exist, according to Beddoe, between the liability to consumption and the colour of the hair, eye, and skin.

Correlation regularly exists between homologous parts ; indeed, it is the cause of the great degree of resemblance between corresponding organs of the body—e.g., the right and left side of most symmetrically-built animals—though it is known that the resemblance is rarely complete, both arms or both legs normally differing slightly from each

other. There is a certain amount of correlation between the length of the legs and that of the arms, but less than in the previous case ; and there exists less correlation still between the length of the limbs and that of the face. In short, we see that when one organ varies, the other correlated organ varies with it to a certain extent. What we want to find is a measure of how much the second organ varies ; in other words, we want to know the degree of correlation between the organs. But correlation exists, not only between the organs of the same individual, but it extends also to characteristics belonging to separate individuals. For instance, we can compare the height of fathers with that of their sons or that of brothers. In all these cases the method of determining the degree of correlation is the same.

For this purpose we proceed in the following manner : We measure, let us say, the heights of a certain number of fathers and the heights of the same number of sons, taking one son for each father, and arrange all fathers of equal heights into groups (each group forming what is called a " class "), so that we get a class of fathers of 62 inches, 63 inches, and so on up to 76 inches height. We find, then, that the fathers have sons of varying heights. For instance, in an imaginary example given by R. H. Lock we have, out of 4,503 fathers and their respective sons, fourteen fathers with a height of 62 inches. Their sons have different heights, distributed as follows :

Heights of sons in inches	63	64	65	66	67	68	69	Mean height of sons, 65·5 inches.
Frequency ..	1	2	3	4	2	1	1	Total number of sons, 14.

Such a series of sons, giving the frequency of sons of different heights for a given class of fathers, is called an " array." The mean height for the whole array of sons can easily be calculated—it is 65·5 inches. We see that, though the fathers of 62 inches height have sons ranging in height from 62 inches to 69 inches, the average or mean

height of all the sons together is 65·5 inches. We now construct the arrays of sons for each class of fathers of all given heights from 62 inches up to 76 inches. For instance, the array of sons for fathers of 63 inches is :

Heights of sons $\}$ 63 64 65 66 67 68 69 70 71 72 $\{$ Mean height of
in inches $\}$ .... $\{$ sons, 66 inches.

Frequency .. 2 4 10 16 9 3 3 1 1 2 $\{$ Total number
.... $\{$ of sons, 51.

Arranging all these arrays one underneath the other, we get a " Correlation Table," as given in Fig. 71. Here we see the different classes of fathers arranged in the first vertical column, and the arrays of sons for each class of fathers in the horizontal lines. Contrariwise, the arrays of fathers belonging to each class of sons having the same height are represented in the vertical columns, the different classes of sons being arranged in the first horizontal line. The mean height of each array of sons we find in the last right-hand column, while the mean height of the arrays of fathers, each belonging to a given class of sons, is found in the lowest bottom line. The mean of all the arrays together is given in the right-hand corner : it is 69 inches. This is the average or mean height of the *whole* population, and is designated by P.

If we now compare the height of each class of fathers with the *mean* height of their sons—*i.e.*, the mean of the array of sons belonging to each class of fathers—we can formulate a definite law, viz. :

Heights of Fathers.			*Mean Heights of Sons.*	*Heights of Fathers.*			*Mean Heights of Sons.*
Inches.			*Inches.*	*Inches.*			*Inches.*
62	..	..	65·5	70	..	..	69·5
63	..	..	66·0	71	..	..	70·0
64	..	..	66·5	72	..	..	70·5
65	..	..	67·0	73	..	..	71·0
66	..	..	67·5	74	..	..	71·5
67	..	..	68·0	75	..	..	72·0
68	..	..	68·5	76	..	..	72·5

CORRELATION TABLE.

Heights of fathers (in inches) across the top; Heights of sons (in inches) down the side.

Heights of sons (in inches)	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	Total fathers for each class of sons	Means of arrays of fathers
62		1	2	3	4	2	1	1								14	65.5
63		2	4	10	16	9	3	3	1	1	2					51	66.0
64	2	4	6	12	21	18	10	6	3	1	1					84	66.5
65	5	11	12	17	33	42	30	17	12	10	4	1				194	67.0
66	4	15	16	31	49	57	55	45	36	18	12	2	2			342	67.5
67	2	10	20	42	58	85	101	84	59	41	18	10	2			532	68.0
68	1	5	10	32	61	102	127	135	105	56	31	10	4	1		680	68.5
69		2	6	14	45	83	132	179	130	82	48	15	6	2		744	69.0
70		1	3	12	31	54	103	127	128	99	56	28	6	4	1	653	69.5
71			1	10	18	40	51	89	103	85	57	45	19	9	2	531	70.0
72				3	15	17	28	46	57	55	45	30	18	16	4	334	70.5
73				1	2	10	11	16	37	39	35	18	12	10	4	195	71.0
74					2	2	4	7	9	17	19	9	6	4	2	81	71.5
75							1	2	4	12	15	10	4	3	1	52	72.0
76								1	1	3	3	4	2	1	1	16	72.5
Total Sons for each Class of Fathers	14	51	84	194	342	532	680	744	653	531	334	195	81	52	16	4503	69.0
Means of Arrays of Sons	65.5	66.0	66.5	67.0	67.5	68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5	69.0	—

Fig. 71. (After Lock.)

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Height of Fathers.   *Mean Height of Sons.*
Inches.   *Inches.*
69   69

Fathers below the average height have sons of a mean
height greater than that of the fathers (the left-hand
column) ; fathers above the average height have sons of a
mean height less than that of the fathers (the right-hand
column), while fathers of average height (69 inches) have
sons of average height.   This proves a distinct correlation
between the heights of father and son.   But we want
further to measure the amount of this correlation.   In
order to do this we construct from the given data a
diagram of correlation in the following way : We plot off
on a horizontal line the heights of the fathers in equal
distances from 62 to 76 inches, do the same on a vertical
line for the heights of the sons, and complete the square.
We draw the diagonal CD of the square thus constructed,
which goes through all the points where the heights of
fathers and sons are the same—*i.e.,* where the horizontal
and vertical lines indicating equal heights cut each other.
If we now mark the mean of each array of sons on their
respective horizontal lines in such wise that each mean
comes to lie on the vertical which indicates the corre-
sponding class of fathers to which that array of sons
belongs—*i.e.,* point *a,* indicating the mean 65·5 inches of
sons belonging to fathers of class 62 inches, lies on the
horizontal line 65·5 inches and on the vertical 62 inches ;
point *b* lies on the horizontal 66 inches and on the vertical
63 inches, etc.—we can draw a straight line AB going as
nearly as possible through all the points thus indicated.
Both lines, CD and AB, cut each other in O, which, as can
be seen, lies on the horizontal and vertical lines indicating
the mean of the population P = 69 inches.   We have
now in the slope of the line AB a measure of the correlation
between the heights of the fathers and that of the sons
plotted on the lines CD and AB respectively.   If AB
coincides with CD, the points *a, b, c, d,* etc., would all fall

on the cross-points of the horizontals and verticals drawn for equal heights—*i.e.*, the heights of the sons would be identical with that of the fathers, and we should have complete correlation. On the other hand, if the line AB were horizontal going through O, the height of all the
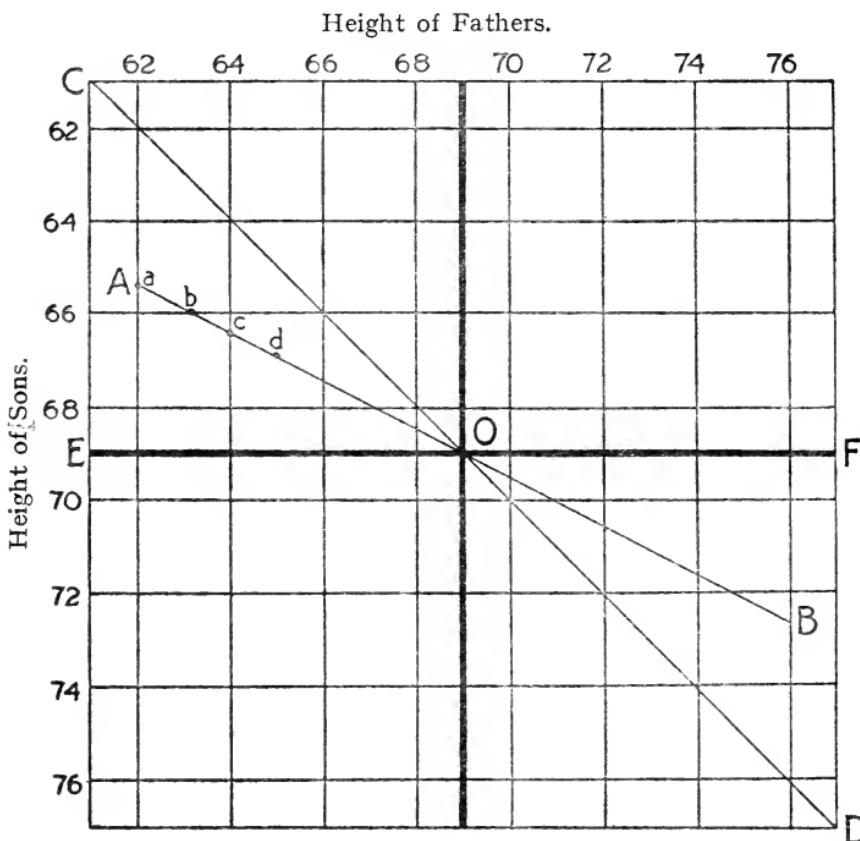
FIG. 72.—DIAGRAM OF CORRELATION. (After Lock.)

sons would be that of the average population, 69 inches, irrespective of the class of fathers to which they belong— *i.e.*, there would be no correlation between the height of the fathers and that of the sons, for all the fathers, irrespective of their own height, would have sons of the same medium

height, 69 inches. We can now measure the slope of the
line AB mathematically by the tangent of the angle AOE.
If this angle is 45 degrees—*i.e.*, if AB fall on CD, its value
tan∢AOE = 1 ; if the angle is 0 degree—*i.e.*, if AB fall
on EF, its value = 0. The correlation varies therefore
between 1 and 0, and is the greater the nearer it is to 1.
In our case the slope would be expressed by $\frac{1}{2}$ or 0·5. This
is called the " Coefficient of Correlation," or *r*, and gives
us the measure of correlation between the heights of the
fathers and that of their sons.

Now, what does this mean exactly ? We have seen that
the heights of the fathers are represented in our diagram
by CD, that of the corresponding arrays of sons (taking
each time the mean of the array) by AB, and the height of
the average population by EF = 69 inches. We learn
from the diagram that when the father is 62 inches high
the son is on an average 65·5 inches ; while the father is
7 inches below the average of 69 inches, the son is only
3·5 inches below it—*i.e.*, only half that amount. When the
father is 75 inches high, or 6 inches above the average, the
son will be on an average only 72 inches—*i.e.*, only 3 inches
above the average, again half of the father's amount. The
same holds good for any given class of fathers and their cor-
related sons. In other words, the deviation of the son from
the mean height of the population (P) is half the amount
of the deviation of the father from P. If P is the mean
height of the population, and D is the deviation of the
father from P, then P±D expresses the height of the
father (+ if he is above the average, — if he is below it),
while the average height of his sons would be P±$\frac{1}{2}$D. In
short, we find the son deviates less from the mean of the
population than does the father ; or, in other words, the
son regresses from the father towards the mean of the
population.

We see, then, that Correlation and Regression are the
same, but viewed from different standpoints. While cor-
relation expresses by how much the son resembles his

father, regression tells us by how much the son is nearer to the mean of the population than his father, both values being the same.

As there is regression from father to son, so there is, on the other hand, regression from son to father—*i.e.*, the father will on an average be more mediocre than a given son. (We only need to compare the figures for the different classes of sons given on the top line of Fig. 71 with those at the bottom line indicating the mean heights of the corresponding arrays of fathers.) Further, there is regression from grandfather to grandson, and *vice versa.*

Galton has given in his classic work on *Natural Inheritance* " the coefficients of correlation " for stature as follows :

Mid-parent and son	$\frac{2}{3}$	Uncle and nephew	$\frac{2}{9}$
Father and son	$\frac{1}{3}$	Grandson and grandparent	$\frac{1}{9}$
Son and father	$\frac{1}{3}$	Cousin and cousin	$\frac{2}{27}$
Brother and brother	$\frac{2}{3}$		

NOTE.—This would mean that if the stature of the mid-parent is $P \pm D$, that of the coresponding son would be $P \pm \frac{2}{3} D$, while if the stature of the father is given as the same, $P \pm D$, that of the son would only be $P \pm \frac{1}{3} D$, and so on for the other cases.

Karl Pearson's coefficients of correlation have somewhat different values. We must here shortly explain the term " mid-parent " as introduced by Galton. As a son inherits from both his parents, father *and* mother, the peculiarities of stature from both parents will be added in the filial inheritance, and the coefficient of correlation, instead of being $\frac{1}{3}$, is $\frac{2}{3}$. For the purpose of calculation Galton introduced the term " mid-parent "—that is, according to his own explanation, " an ideal person of composite sex, whose stature is halfway between the stature of father and the transmuted stature of the mother." In order to transmute the stature of the mother into that of the father, the stature of the mother is reckoned of that height which it would be if the mother were of the male sex. Galton found that for this purpose 1 inch has to be added to each

foot of the height of the mother—*i.e.*, a mother of 5 feet high
would have to be reckoned as of the stature 5 feet 5 inches.

At first sight Galton's Law of Regression towards
mediocrity seems something abnormal and contrary to the
fact that children inherit the traits of their parents. But
that is due to a misunderstanding. It does not assert that
all the children of any given class of parents are mediocre :
it asserts only that *on the average* the children of any given
parents will be more mediocre than the parents themselves.
It must be well understood that only the average of all
the children of a given class is nearer to the general mean.
This does not exclude parents of a given class from having
children of different types. For instance, fathers of
64 inches height have, according to our correlation table,
sons of various heights, ranging from 62 inches up to
72 inches—some smaller than the fathers, some taller, some
of the same height ; but the average of all the sons together,
which works out at 66·5 inches, is nearer to P (or 69 inches)
than is the height of the fathers, which is 64 inches. It still
remains true that fathers of a greater height have on the
average sons of greater height than fathers of smaller
height. We need only compare the heights of fathers and
sons as given in the table (p. 157) in order to see this at
once. In fact, we may sum up the contents of the cor-
relation table, as H. M. Vernon has done, as follows. The
number of children of given parents is :

Parents.		*Children.*		
		Tall.	*Medium.*	*Small.*
Tall		many	moderate	very few
Small		very few	moderate	many
Medium		moderate	many	moderate

All that the Law of Regression says is, that in each instance
the sons will *on an average* be nearer to the medium height,
as expressed by the general population, than their fathers.

Why should there be regression ? Does it agree with our general notion of inheritance ? Though the law of regression seems to be something unexpected, yet it is completely in accordance with the known facts of heredity. We have found that in any given population the medium variations— be they of height or any other characteristic—are the most frequent. Now, the forefathers of any given son will, according to the law of probability, be on the average mediocre people, and as the son inherits, not only from his parents, but from all his ancestors, it is, to use an expression of Karl Pearson's, " the weight of this mediocre ancestry " which drags down any exceptional gifts the son may inherit from his parents. " But the law of regression," says Galton, " is even-handed ; it levies an equal succession tax on the transmission of badness as of goodness. If it discourages the extravagant hopes of a gifted parent that his children will inherit all his powers, it no less discountenances extravagant fears that they will inherit all his weakness and disease."

Correlation has been found to apply not only to stature of man, but also to eye-colour, and even, as Karl Pearson has shown, to mental and moral characteristics. The co-efficient of correlation gives us therefore a convenient measure of nearness of relationship between family members. Thus, the Regression Table of Galton on p. 162 gives us at the same time a numerical value for the degree of kinship between the relations mentioned. The coefficient of correlation has therefore also been called the coefficient of heredity. We see, *e.g.*, that brothers are twice as closely related to each other as father and son.

IV.—FURTHER CORRELATIONS.

(a) ASSORTATIVE MATING.

We have seen that there is correlation between parents and children and all other degrees of kinsmen whose relationship can be expressed in definite numerical values.

But Pearson has extended still further the method of measuring the correlation between given characteristics of two individuals. He compared husband and wife with regard to stature and eye-colour, and found a distinct correlation for both characteristics in married couples. By constructing, according to the usual method, a correlation table of the statures of 1,000 husbands and wives, he found a decided tendency for " like to mate with like "— *i.e.*, tall men married on an average tall women, medium men women of medium height, and small men small women. A similar result was obtained for eye-colour. This shows definitely that, contrary to the popular belief that " opposites attract each other," there is, as Pearson has called it, " assortative mating " with regard to stature and eye-colour. " In fact, husband and wife are," according to him " for one of these characters " (stature) " more alike than uncle and niece, and for the other " (eye-colour) " more alike than first cousins."

(*b*) FERTILITY.

So far we have dealt in detail with the correlation of such characters as had a definitely visible outward expression, and could therefore easily be measured. But, as we said at the beginning of our chapter on correlation, there are other characters which, being physiological or functional variations of the organism, are more elusive, though they, too, can be shown to come under the law of correlation. One of these characters is fertility.

That relative fertility plays an essential rôle in the origin of species has been an acknowledged fact ever since Darwin, and various theories have been advanced in order to explain how the divergence of new varieties from the mother-type and their final separation into distinct species take place. Relative sterility between the incipient species seems to be an essential factor. Now, Pearson has been able to show that there is a definite correlation between certain characters

of given individuals and their fertility. For instance, he found by biometrical calculations for man that tall women procreate faster than small women, also that dark-eyed people are more fertile than light-eyed. This would naturally lead to a gradual modification of the race into the direction of the more prolific type. " Genetic Selection," as this process has been called, is then, we see, an active force in producing a progressive change of type, and must, if there is differential fertility between various types, lead to a differentiation of such types. But, further, that fertility really varies Pearson was able to demonstrate in various cases. Thus he found, *e.g.*, that of 176 Shirley poppies, with 4,443 capsules, arranged in the following array,

Stigmatic Bands } 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

Frequency 1 11 32 56 148 363 628 925 954 709 397 155 51 12 1

the poppies with twelve and thirteen stigmatic bands—*i.e.*, those with the greatest frequency—were the most fertile ; those with eleven and fourteen bands were less fertile, and those with the extreme number of bands on either side had practically no seeds at all. " Fertility is, then," according to Pearson, " not only uniformly distributed among all individuals, but for stable races there is a strong tendency for the character of maximum fertility to become one with the character which is the type " (*i.e.*, that of the greatest frequency). In a new environment a change of the old centre of fertility may take place, and other types of character previously less fertile may now become more fertile.

There is one more point to be mentioned in connection with these problems, which we have only lightly touched upon. The modification of the character of the race in a given direction can take place only if the fertility of a given type of individuals is inherited—*i.e.*, if all the successive generations of that type exhibit the same

amount of fertility. Pearson has proved the inheritance of fertility from mother to daughter, from father to son, and from paternal grandmother to granddaughter, in accordance with the Law of Ancestral Inheritance, to which we now turn our attention.

V.—THE LAW OF ANCESTRAL INHERITANCE.

We have in a previous chapter (IV.) shown the share that parents have in the constitution of their children, and also the contribution made by ancestors to any given individual. Dealing there with the germ-cells as the constituent factors, we discussed the various possibilities of inheritance. We could there only point out what were the possibilities, without at the same time being able to say what occurs in any given instance. Now, the statistical method takes us a little farther. Without telling us what will happen in an individual case, it can at least give us information as to what will, on an average, be the frequency or probability of such a case. We may not know who is going to die, or from what cause any given person is going to die in any year, but statistics enable us to tell how many die on an average in any given year, and from what diseases—useful knowledge, as far as it goes. In the same way, though we cannot learn how much each individual parent and ancestor contributes towards the constitution of a given organism, the biometrical method enables us to formulate a " Law of Ancestral Inheritance," which tells us how much *on the average* is the amount of contribution of each parent and each ancestor.

The contributions of the several progenitors of any given individual have been calculated by Galton on the basis of the Coefficient of regression as follows : " The two parents between them contribute, *on the average,* one-half of each inherited faculty, each of them contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth, and so

on, the sum of the series $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \ldots$ being equal to 1, as it should be.* Or, as expressed by Pearson, this series would stand :

$$0.5 + (0.5)^2 + (0.5)^3 + (0.5)^4 + \ldots (0.5)^n = 1,$$

though, using his own coefficient of correlation, he found slightly different values.

The diagram on p. 169 illustrates Galton's Law of Ancestral Inheritance. Only four generations are here recorded in the square (the original individual, equal to the whole square, being numbered 1, the two parents 2 and 3, the four grandparents 4, 5, 6, 7, etc.), but their number could be increased indefinitely.

Viewed from another standpoint, this law gives us " the average amount of resemblance between an individual and any particular ancestor."

The above law being based on the Coefficient of Correlation, Pearson has shown a most important corollary to flow from it. If we introduce artificial selection at any given point of the ancestry, what will be the result on the progeny ? Pearson has calculated the exact values of any selected character for the successive generations. Thus, if we choose stature in man for selection, and select a mid-parent having a height, h, above the average population, P, then the offspring (first generation) of this mid-parent will differ only $\frac{2}{3}$ h, or 0.62, from P. The second generation, having parents and grandparents of the selected type, will differ only by 0.82 h ; the third generation by 0.89 h, and so on up to 0.92 h. So that finally a race could be bred all the members of which would not

* This law must not be confused with the statement on p. 75 about the " Quantitative Contribution of Ancestors." It was there stated that the contribution of each parent is half, as each parent furnishes half the hereditary substance of the child. This is so, but it must be remembered that each parental germ carries within itself the constituents of the whole ancestral line. If we subtract the contributions of all these ancestors, the parents themselves contribute each only one-quarter to the constitution of the child.
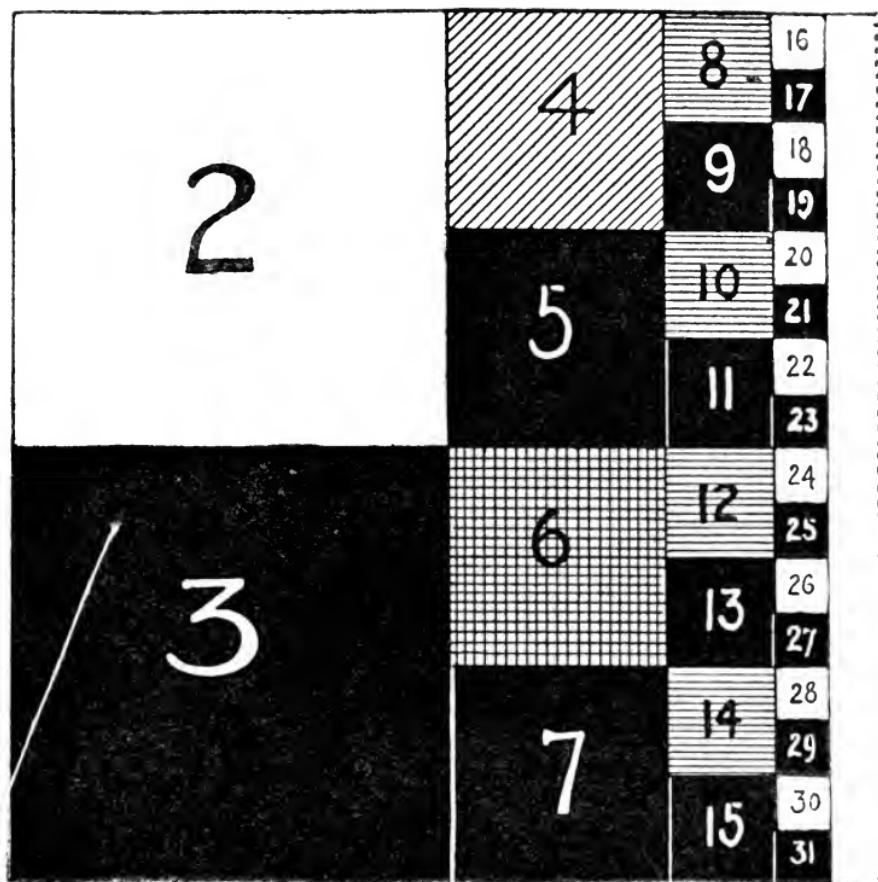
FIG. 73.—LAW OF ANCESTRAL INHERITANCE.

(*From J. A. Thomson, " Heredity."*)

be much less than the original mid-parent. If the original mid-parent differed from the mean population by h, his height would be $P + h$:

$$
\text{The height of the}
\begin{cases}
\text{mid-parent} & \quad .. \quad P + h \\
\text{first generation} .. & \quad .. \quad P + 0.62\ h. \\
\text{second generation} & \quad .. \quad P + 0.82\ h. \\
\text{third generation} & \quad .. \quad P + 0.89\ h. \\
\text{last generation} .. & \quad .. \quad P + 0.92\ h.
\end{cases}
$$

22

"We see," says Pearson, "selection is not checked by regression. Regression is merely the result of mediocre ancestry; the moment we give selected ancestry, the regression begins to diminish, and in a few generations is hardly sensible."

If, however, selection stops and general inbreeding of the selected stock takes place, decline at once sets in. The ratios have been calculated by Pearson as follows, according as selection stops after the first, second, third, or tenth generation of selection. We give the values for the first and last cases above mentioned :

					First Generation.		*Last. Generation.*
Last offspring of selection				..	0·62 *h.*	..	0·92 *h.*
First generation of inbred stock				..	0·59 *h.*	..	0·86 *h.*
Second	,,	,,	,,	..	0·56 *h.*	..	0·81 *h.*
Third	,,	,,	,,	..	0·52 *h.*	..	0·77 *h.*
Tenth	,,	,,	,,	..	0·35 *h.*	..	0·51 *h.*

A most important conclusion follows from the consideration of the above results. While we have seen that an exceptional characteristic arising from mediocre ancestry is bound to revert within a few generations to the general level of mediocrity displayed by those ancestors, it becomes apparent that, if the characteristic be selected for a number of generations, it will, with continued selection, breed true in all successive generations within 1 per cent. of its original value.

As Galton has expressed it : " A fundamental distinction may exist between two couples whose personal faculties are naturally alike. If one of the couples consists of two gifted members of a poor stock, and the other of two ordinary members of a gifted stock, the difference between them will betray itself in their offspring. The children of the former will tend to regress, those of the latter will not. The value of a good stock to the well-being of future generations is therefore obvious." It follows from this

that, as we draw our geniuses from the great mass of population, and not from a specially selected stock, the average genius we meet is more likely to be an exceptional variation of a mediocre stock than a common variation of an exceptional stock. This accounts for the fact that the sons of geniuses are often so disappointing.

A great deal of controversy has arisen as to how far the Law of Ancestral Inheritance holds good, its value being altogether denied by the most thoroughgoing Mendelians. There is no doubt that the Law of Ancestral Inheritance, as stated by Galton and Pearson, is not applicable to every kind of inheritance, for it presupposes that each ancestor contributes some quota towards the total heritage of a given characteristic, while in prepotent and Mendelian inheritance certain ancestors may have no share whatever in the production of such character in certain offspring. But, as we said already at the conclusion of our chapter on Mendelism, it may well be that there are two or more series of phenomena needing explanation. While Galton's law would apply to cases of intra-racial heredity (inheritance between members of the same race), it would not cover the cases of Mendelian hybrids. A reconciliation between these laws may in the near future, perhaps, not be impossible, seeing that G. Udny Yule has expressed the conviction that " Mendel's Law and the Law of Ancestral Heredity are not necessarily contradictory statements, one or the other of which must be mythical in character, but are perfectly consistent one with the other, and may quite well form parts of one homogeneous theory of heredity."

CHAPTER X

CONCLUSIONS

HEREDITY AND ENVIRONMENT.

WE can distinguish three stages in the evolution of every science : First we have the period of blind speculation, of fanciful metaphysical explanations, without the slightest attempt to investigate or verify them. Then comes the age of reaction—the time of studious collection of facts and their careful classification—generally coupled with a ruthless disdain of all theorizing. So far as the systematization of knowledge goes, it forms the absolutely essential spade-work for all sciences—a very necessary and laborious undertaking. But a science, to be " knowledge " in the real sense of the word, must be more than a mere collection of facts. It must furnish us with practical solutions for purposes of everyday life ; it must not only be able to tell, but also to foretell. In other words, a science, in order to become a real science, must contain certain leading principles, serving at the same time as a unifying bond of the organized knowledge and giving us working ideas for our guidance in practical life.

It is not going too far to assert that the Science of Heredity has just entered into its third phase. In the mass of conflicting statements and hypotheses certain facts have come to stand out with sufficient clearness to afford us light enough to see the direction in which we have to travel. And be it understood and impressed once more : Procreation being the foundation of all life, the science of heredity forms the basis of the science of life, and its

principles must therefore be considered the fundamentals of all Social Science. Man, though far above the brute creation by reason of his higher emotions and understanding, is yet essentially an animal. Life, and with it social life, cannot be understood without a thorough grasp of the underlying biological phenomena. Though sociological problems cannot be solved on the strength of biological principles alone, it is these latter which—instead of being neglected, as they generally are—have first to be sifted and taken account of in order to find a stable basis for fruitful discussion of the " social question."

To come nearer to our subject, what is the central problem set before us in the foregoing chapters ? We have learnt the facts about the inheritance of characters, the method of their transmission in the individual, and their distribution in a given population. We have discussed the influence of environment and other factors in the production of certain characteristics. Finding that there are only these two sets of potent factors, the hereditary and the environmental, in the evolution of races, we come to see that the consideration of social progress from a biological point of view resolves itself into the question of the relative values of these factors. Indeed, we may express the whole matter before us as essentially the problem of " Heredity and Environment."

We have touched upon this subject repeatedly during the course of our book, but shall here deal with it coherently, and also draw some practical conclusions from it. For the question is of vital importance, seeing that from our decision on this point—the relative influence of the hereditary and environmental factors on the race—depends the progress and welfare of future generations.

To treat of environment first, we must point out at the outset that good and favourable conditions are an absolute essential for the proper development of every living organism. The normal and healthy growth of each individual is possible only on the appropriate stimuli

being supplied by the forces of the outside world, which are worked up by the growing body. No sensible person would expect to rear an oak from an acorn without putting it into the proper surroundings—the right kind of soil, etc. But whilst positing so much—a fact which every scientist admits, nay, insists upon, as an essential physiological requirement of the growing organism—we are not committed to any further implications involved. For instance, it does not follow as a deduction from the above fact that, as environmental influences affect the individual to a certain extent, such effects react, as a matter of course, on the subsequent offspring. This is, indeed, the assumption which the Lamarckian makes in order to explain the evolution of species by the accumulated results of acquired characters. We have already given in full the arguments against the Lamarckian theory, showing that so far our knowledge does not warrant any such assumption. Environment plays an important rôle in the evolution of species, but, according to the now generally accepted view of most scientists, not in the manner represented by Lamarck—*i.e.*, by the directly inherited effect of changed surroundings. On the contrary, according to Darwin's theory of Natural Selection, the environment does not alter the characteristics of the individual directly, but only selects such individuals as possess certain characters most suitable to that environment, the remaining members of the species being weeded out in the struggle for existence. By thus constantly eliminating those unfit for the prevailing conditions, the constant change of environment leads to a progressive change of the species, thus bringing about its gradual transformation. We see that the rôle which environment plays in the evolution of species is not direct, but indirect, through its selective action on the already existing variations of the members of a given race.

Coming now to the second part of the problem, the hereditary factor, we see, as has been pointed out many times before, that these variations are given qualities, being due

to influences already existent in the germ, and therefore heritable. Whatever environmental influences may do, they can only work with these fixed hereditary tendencies. And it is for this very reason that the potentialities expressed in the germ are of the utmost importance, forming, as they do, the material for the progressive evolution of the race.

It is, then, to these fundamental hereditary qualities that we have to devote our attention. Natural selection being the keystone of the evolutionary process, we must look to the same principle as a guide for the solution of the " social question." For this problem does not mean only the quest for the betterment of the individual born into society—a problem which depends for its solution on the procurement of favourable conditions for all (this is generally called the " social problem," and thought to be its sole and whole content) ; the problem implies, furthermore—and this is its most important part—the gradual betterment of the race ; in other words, the progressive development of man, be it in his physical, intellectual, or moral capacity. Those who maintain that a change of environment alone, however favourable, will have permanent effects on succeeding generations, basing, as they do, their belief on the presumed inheritance of acquired characters, have, as repeatedly shown, little grounds for such an assumption. Whatever environment may do for the individual, its effects are not embodied as part and parcel of the heritage of the progeny. " No degenerate and feeble stock," says Karl Pearson, " will ever be converted into healthy and sound stock by the accumulated effects of education, good laws, and sanitary surroundings. Such means may render the individual members of the stock passable if not strong members of society ; but the same process will have to be gone through again and again with their offspring, and this in ever-widening circles, if the stock, owing to the conditions in which society has placed it, is able to increase in numbers."

But man has become more and more master of his environment. Whilst still subject to the natural law of the " Survival of the Fittest," he has been able to change his surroundings consciously, to ameliorate, by the combined action of his humanitarian sentiments and better hygienic arrangements, the rigour of Natural Selection, so as to allow his weaker brethren to survive and leave progeny. Far from our wishing to put an end to this so-called interference with Natural Selection, we should see in it one of the most welcome signs of advancing civilization, and one which is bound to go on in ever-increasing ratio. For what is civilization more than a constant curbing and mastering of the blind forces of nature ? If this is so, " the suspension of that process of Natural Selection which in an earlier struggle for existence crushed out feeble and degenerate stocks, may be a real danger to society, if society relies solely on changed environment for converting its inherited bad into an inheritable good. If society is to shape its own future—if we are to replace the stern processes of natural law, which have raised us to our present high standard of civilization, by milder methods of eliminating the unfit—then we must be peculiarly cautious that in following our strong social instincts we do not at the same time weaken society by rendering the propagation of bad stock more and more easy " (Pearson).

What, then, is our final social remedy ? Seeing that no permanent improvement of the race is possible, according to the Lamarckian method, by " Nurture," we have to fall back on the second alternative, the " Nature " of the stock. In other words, as has been so felicitously expressed by D. G. Ritchie, we must supplant " Natural Selection " by " Rational Selection."

We have already seen that there is a close relationship between the character of parents and that of their children. If we refer to the table on p. 158, we find that the greater the height of the parents the taller are, on the average, the children, and *vice versa*. Galton has further amplified his

investigations, and come to most interesting results. In the following table he has arranged a population of 10,000 individuals in a series. M denotes mediocrity, while $+1°$, $+2°$, etc., and $-1°$, $-2°$, etc., denote talents in the plus and minus direction respectively—*i.e.*, talents above or below mediocrity (each talent being reckoned as equal to the Probable Error of the group—*i.e.*, if we take M equal, *e.g.*, to the average height, 5 feet 8 inches, each talent would be expressed by $q = 1\frac{3}{4}$ inches). In the second row we find the classes marked by letters from R upwards to V, and from *r* downwards to *v* (R referring to a class receiving more than M, but less than $M + 1°$, S receiving more than $M + 1°$, but less than $M + 2°$, etc., and the same on the negative side; *i.e.*, R exceeds the height 5 feet 8 inches, S exceeds 5 feet $9\frac{3}{4}$ inches, etc.). Beneath these is given the frequency of each class. We see here again that the mediocre quality is shared by the greatest number of individuals, and the qualities in the plus and the minus direction decrease in number towards both ends of the series. From this table, then, we know the actual distribution of talent in a population. We see, *e.g.*, that only 35 out of 10,000, or 1 : 300, are of the highest talent V.

$-4°$	$-3°$	$-2°$	$-1°$	M	$+1°$	$+2°$	$+3°$	$+4°$		
v (and below).	*u*	*t*	*s*	*r*	R	S	T	U	*V (and above)*.	*Total.*
35	180	672	1613	2500	2500	1613	672	180	35	10,000

FIG. 74.—FREQUENCY OF TALENTS. (After Galton.)

But, knowing thus much, the further question arises : How is this class V of offspring distributed with regard to their parents ? or, in other words, in what proportions do the different classes of parents contribute to any given class of children ? This is a most important inquiry, which gives us the key for the practical solution of the whole question. Now, Galton gives us the following table of Descent of Qualities in a Population :

DESCENT OF QUALITIES IN A POPULATION.

Per 10,000 Fathers or Mothers		35	180	672	1614	2500	2500	1614	671	180	35	10,000
Names of Classes		V	U	T	S	R	r	s	t	u	v	**Totals**
Sons or Daughters of 35 {Fathers or Mothers} of Class V	V	6	10	12	6	1	—	—	—	—	—	35
,, 180 ,,	U	10	33	61	52	20	4	—	—	—	—	180
,, 671 ,,	T	10	57	170	234	150	44	7	—	—	—	672
,, 1614 ,,	S	5	47	224	509	512	253	57	6	—	—	1613
,, 2500 ,,	R	3	18	140	510	860	678	248	42	3	—	2502
,, 2500 ,,	r	—	3	42	248	678	860	510	140	18	3	2502
,, 1614 ,,	s	—	—	6	57	253	512	509	224	47	5	1613
,, 671 ,,	t	—	—	—	7	44	150	234	170	57	10	672
,, 180 ,,	u	—	—	—	—	4	20	52	61	33	10	180
,, 35 ,,	v	—	—	—	—	—	1	6	12	10	6	35
Total 10,000 Fathers or Mothers		34	168	655	1623	2522	2522	1623	635	168	34	10,004

NOTE.—The agreement in distribution between fathers (or mothers) and sons (or daughters) is exact to the nearest whole percentage. The slight discrepancy in the ten-thousandths is mainly due to the classes being too few and too wide; theoretically they should be extremely numerous and narrow.

Fig. 75. (After Galton.)

In the table we find 10,000 fathers (or mothers) arranged vertically in the left-hand column into classes (from V down to v), while the arrays of sons (or daughters) belonging to each class of fathers are given in the horizontal lines. We can thus at a glance read off, not only the numerical proportions of each class of sons belonging to a given class of fathers, but also, *vice versa*, the numerical contribution of each class of fathers to a given class of sons.

Thus, we see that fathers of the V class have sons :

$$\text{Fathers V} \begin{cases} \text{Sons} \ .. & .. & \text{R} & \text{S} & \text{T} & \text{U} & \text{V} \\ \text{Frequency} & .. & 1 & 6 & 12 & 10 & 6 \end{cases}$$

while, on the other hand, sons V belong to the following fathers :

					Sons V.		Per Cent. of Sons.
35	Fathers	V	..	..	6	..	17·0
180	,,	U	..	..	10	..	5·5
671	,,	T	..	..	10	..	1·6
1614	,,	S	..	..	5	..	0·3
2500	,,	R	..	..	3	..	0·12

We see that the sons of the highest talent V are derived from fathers of the classes V to R, all being on the positive side of mediocrity ; and, furthermore, that the percentage of such sons rapidly falls with the decrease of talents in the fathers—fathers of the V class yielding 17 per cent. of sons of class V, those of R only 0·12 per cent. Something similar, of course, applies to all the other classes of fathers and sons. We have, for instance, the same proportions between fathers and sons on the negative side, the lowest class of fathers, v, giving the greatest percentage of sons of that type.

This definitely proves in figures how important the quality of parents is for the production of quality in off-spring. Coupled with the knowledge that favourable conditions, however much prolonged, cannot alter the hereditary descent of qualities, the conclusion is forced upon us that the only means of eliminating once for all

the dregs of society (whosoever they may be), is to prevent them from multiplying by propagating their own kind. On the other hand, it is apparent that, if we desire to breed a high type of individuals, the chances of success are very much greater if we select for propagation fathers of a high type, and even greater still, as Galton has shown, when there is coupled with it talent from the mother's side.

Additional weight is added to these deliberations by other facts already adduced with regard to the action of selection on the rearing of stock, as elaborated by Pearson.   It has been shown in Chapter IX. that, while good stock springing from mediocre ancestry regresses within a few generations to the mediocre level of its ancestry, good stock bred from a succession of selected generations finally regresses barely 1 per cent. from the selected value.   In other words, by selecting good stock for a few generations we can insure that they will breed practically true for an infinite number of generations.   " Looked at from the social standpoint," says Pearson, " we see how exceptional families, by careful marriages, can even within a few generations obtain an exceptional stock, and how directly this suggests assortative mating as a moral duty for the highly endowed.   On the other hand, the exceptionally degenerate, isolated in the slums of our modern cities " (and we would add, *not* only in the slums), " can easily produce permanent stock also—a stock which no change of environment will permanently elevate, and which nothing but mixture with better blood will improve.   But this is an improvement of the bad by a social waste of the better.   We do not want to eliminate the bad stock by watering it with good, but by placing it under conditions where it is relatively or absolutely infertile."

Further, Mendelism, not less than all the other evidence already brought into array, proves conclusively how the nature of the progeny depends essentially on the gametic constitution of the parents.   Nay, it has been shown that

with better knowledge we shall be able to create new and durable types, combining desirable qualities which were previously separated in different stocks, without at the same time having to cope with the heavy burden of contaminated strains.

We thus arrive at our final conclusion that the only means of permanently raising the standard of the race consists in the conscious and deliberate application of the method of rational selection—*i.e.*, selective breeding, or, as it has been aptly named by Galton, " Eugenics." This becomes the more imperative since the higher types exhibit, as can be amply shown, a lessened fertility, often by their very prudence and foresight voluntarily checking proliferation ; while, on the other hand, the progress of humanitarian sentiments tends largely to keep alive " the precipitate of the socially unfit." Seeing that 25 per cent. of one generation produces 50 per cent. of the next, " it is essential for national fitness," to quote Pearson once more, " that when we suspend the selective death-rate, we should see to it that a selective birth-rate is introduced at the same time." We only need to refer to the great number of persons insane, imbecile, or morally depraved and criminal —and they are not necessarily confined to any one stratum of society—in order to recognize that there is scope for a beginning at least on the negative side of Eugenics. Furthermore, a large field of practical work is open with regard to disease. Without contending that we should give up the fight against disease by a vigorous sanitary campaign against filth and foul air, and should rather weed out consumptive man than the bacillus of consumption (a somewhat wild suggestion made against the scientific adherents of Eugenics), it remains at the same time an imperative duty, as long as disease exists, to create what may be called a moral conscience against propagating inheritable diseases or predispositions to such. We cannot do better than enumerate in full the eugenic rules given by Professor Thomson :

" That the best general constitutions should be mated is the first rule of good breeding.

" That a markedly good constitution should not be paired with a markedly bad one is a second rule, a disregard of which means wanton wastage.

" A third rule is that a person exhibiting a bias towards a specific disease should not marry another with the same bias.

" In other words, every possible care should be taken of a relatively sound stock. The careless tainting of a good stock is a social crime. Every reasonable precaution should be taken to prevent a badly tainted stock from diffusing itself."

" What is above all precious," to quote the same authority, " is the conservation of good stock. No number of veneering modifications—superficial screens of organic defects—can atone for allowing a deterioration of the germinal inheritance to diffuse itself or accumulate. For progress which is really organic—for progress, that is, in our natural inheritance—we must wait, or rather work, patiently. The quest after ' Eutopias ' and ' Eutechnics ' must be associated with an enthusiasm for ' Eugenics.' "

As for moral characteristics, there is no doubt that we cannot but hold them subject to the general biological laws of inheritance. In fact, Pearson has been able to show, as mentioned once before, that mental and moral characters are inherited in the same ratio as physical qualities. It is true, the moral and intellectual powers depend as much as the other physiological functions of the body on the appropriate stimuli supplied by early culture and education ; it is true, the outward expression of these inherent qualities may be modified by the superimposed weight of social sentiments, habits, and customs—the social heritage bequeathed by society to the individual ; but, after all, *how* each individual reacts towards these outside forces depends completely on his intrinsic inherited potentialities. And it would be rash to deny that there are no different

potentialities of the mind in the germ, as there are of the body. We all distinguish between good and bad tendencies ; we all know of different temperaments and intellectual capabilities in families—nay, in the various members of the same family.

It behoves us, therefore, to take a rational view of this question. To quote R. C. Punnett's words at the end of his book on Mendelism : " Education is to man what manure is to the 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."

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GLOSSARY

[L. means derived from Latin; Gr. means derived from Greek. The pages refer to the context of the book, where the word is explained.]

Acquirement, an acquired character.

Adventitious (L. *ad*, to; *venire*, to come), additional.

Algæ (L. *alga*, seaweed), a division of plants embracing seaweeds.

Allelomorph, allelomorphic (Gr. *allelos*, other; *morphē*, form) (p. 124).

Amitosis (Gr. *a*, negative; *mitos*, see **mitosis**), the process of direct cell-division (p. 11).

Amœba (Gr. *amœbē*, change), the lowest single-celled animal constantly changing its form.

Amœboid (Gr. *amœbē*, *eidos*, form), like an amœba.

Amphibian (Gr. *amphi*, both; *bios*, life), animals capable of living both in water and on land, as frogs, etc.

Amphimixis (Gr. *amphi*, both; *mixis*, mixture), sexual union (p. 45).

Amphioxus (Gr. *amphi*, both; *oxys*, sharp), the lancelet fish, pointed at both ends.

Anabolism, anabolic (Gr. *anabolē*, a rising up), the constructive process of assimilation in the body.

Anemone. See **Sea-anemone.**

Animalcule (L. *animalculum*), a small animal.

Antenatal (L. *ante*, before; *natalis*, pertaining to birth), before birth.

Array (p. 156).

Arthropoda (Gr. *arthron*, joint; *pous*, *pod-*, foot), a class of animals with jointed feet, as insects, crabs, etc.

Asexual (Gr. *a*, negative, and sexual), without sex.

Assimilate (L. *ad*, to; *similis*, like), to convert into a like substance, as food in our bodies.

Aster (Gr. *aster*), a star.

Atavism (L. *atavus*, a great-grandfather), reversion to an ancestral type (p. 81).

Atrophy (Gr. *a*, negative; *trophē*, nourishment), a wasting.

Autogamy (Gr. *autos*, self; *gamos*, marriage) (p. 23).

Bacillus (L. *bacillus*, a little rod), lowest single-celled plant-organism.

Bacterium (Gr. *bakterion*, a little staff), lowest single-celled plant-organism.

Biology (Gr. *bios*, life; *logos*, a discourse), the science of life.

Biometrics, biometrical (Gr. *bios*, life; *metron*, measure), the statistical science of life.

Biophor (Gr. *bios*, life; *pherein*, to bear), the smallest living unit of the body (p. 63).

Blastogenic (Gr. *blastos*, germ; *genēs*, producing), arising in the germ (p. 96).

Blastomere (Gr. *blastos*, germ; *meros*, a part), a segment of the dividing ovum.

Blastula (Gr. *blastos*, germ) (p. 47).

Castration (L. *castratio*), emasculation.

Cellular (L. *cellula*, a cell), consisting of or pertaining to cells.

Centrosome (Gr. *kentron*, a sharp point, centre; *soma*, body) (p. 32).

Chætopoda (Gr. *chaitē*, hair; *pous, pod-*, foot), a class of worms, including the earthworm, etc.

Chromatin (Gr. *chroma*, colour) (p. 30).

Chromomere (Gr. *chroma*, colour; *meros*, part) (p. 58).

Chromosome (Gr. *chroma*, colour; *soma*, body) (p. 32).

Class (p. 156).

Conjugation (L. *con*, together; *jugum*, yoke) (p. 17).

Consanguinity (L. *con*, with; *sanguis*, blood), relationship by blood (p. 118).

Crustacea (L. *crusta*, rind), a large class of animals, including lobsters, crabs, etc.

Daltonism (named from the chemist John Dalton) (p. 112).

Darwinism, Darwinian (named from Charles Darwin), the theory of the " Origin of Species," by Darwin.

Degeneration (L. *de*, down; *genus*, kind), deterioration.

Dementia (L. *de*, negative; *mens*, mind), mental enfeeblement.

Determinant (L. *determinare*, to determine) (p. 57).

Determinate (L. *determinare*, to determine) (p. 80).

Deviation (L. *deviare*, to deviate), a divergence (p. 154).

Diathesis (Gr. *dia*, asunder; *tithenai*, to place), predisposition to particular diseases, as gout, etc.

Differential (L. *differentia*, a difference) (p. 77).

Dihybrid, dihybridism (Gr. *di*, twice; L. *hibrida*, a mongrel), a double hybrid (p. 127).

Diptera (Gr. *di*, twice; *pteron*, wing), two-winged insects, as flies, etc.

Diœcious (Gr. *di*, twice ; *oikos*, house), having the two sex-organs upon distinct individuals (p. 22).

Ectoderm (Gr. *ektos*, outside ; *derma*, skin), the external layer of the embryo (p. 48).

Embryo, embryonic (Gr. *embryon*), the young organism in its earliest stages of development.

Embryogenesis (Gr. *embryo, genesis*, generation), the development of the embryo.

Encyst (Gr. *en*, in ; *kystis*, bladder), to become enclosed in a cyst.

Endosperm (Gr. *endon*, within ; *sperma*, seed), the albumen of a plant-seed.

Entoderm (Gr. *entos*, within ; *derma*, skin), the internal germinal layer of the embryo (p. 48).

Epigenesis (Gr. *epi*, upon ; *genesis*, generation) (p. 77).

Epithelium (Gr. *epi*, upon ; *thelē*, nipple), the cell-tissue forming the outer and inner lining of the body.

Eugenics (Gr. *eu*, well ; *genēs*, producing), good breeding (p. 181).

Eutechnics (Gr. *eu*, well ; *technē*, art), good arts, industries (p. 182).

Eutopia (Gr. *eu*, well ; *topos*, place), good surroundings (p. 182).

Evolutio (L. *e*, out ; *volvere*, to roll), an unfolding (p. 77).

Evolution (L. *e*, out ; *volvere*, to roll), the doctrine according to which the higher forms have evolved from the lower.

Fertilization (L. *fertilis*, fertile), the process of fertilizing (p. 42).

Filial (L. *filius*, a son), pertaining to a son or daughter.

Fission (L. *findere*, to cleave), a kind of division (p. 12).

Fœtus, fœtal (L. *feuere*, to bring forth), the animal in the womb in its later stages.

Gamete, gametic (Gr. *gamos*, marriage), the sexual germ (p. 124).

Gastrula (Gr. *gaster*, belly) (p. 47).

Gemmule (L. *gemma*, bud), a little bud (p. 54).

Genetic, genetical (L. *generare*, to generate), pertaining to generation.

Geotropism (Gr. *gē*, earth ; *tropos*, a turn), the tendency to growth downwards.

Germinal (L. *germinare*, to bud), pertaining to the germ.

Germ-plasm (L. *germen*, a bud ; Gr. *plasma*, form) (p. 58).

Hæmophilia (Gr. *haima*, blood ; *philia*, love), a constitutional tendency to bleeding (p. 113).

Heliotropism (Gr. *helios*, sun ; *tropos*, a turn), the tendency to growth towards the sun.

Heredity (L. *heres*, the heir), the organic relationship between generations.

Hermaphrodite (*Hermēs*, a Greek god, and *Aphroditē*, a Greek goddess), a double-sexed organism (p. 24).

Heterodynamous (Gr. *heteros*, other ; *dynamis*, power) (p. 71).

Heterogamy (Gr. *heteros*, other ; *gamos*, marriage) (p. 20).

Heterogeneous (Gr. *heteros*, other ; *genos*, kind), having the constituent elements dissimilar.

Heterologous (Gr. *heteros*, other ; *logia*, relation) (p. 70).

Heterozygote (Gr. *heteros*, other ; *zygon*, yoke) (p. 124).

Homodynamous (Gr. *homos*, same ; *dynamis*, power) (p. 71).

Homogeneous (Gr. *homos*, same ; *genos*, kind), having the constituent elements all alike.

Homologous (Gr. *homos*, same ; *logia*, relation), corresponding in relative position (p. 70).

Homozygote (Gr. *homos*, same ; *zygon*, yoke) (p. 124).

Hybrid (L. *hibrida*), a mongrel.

Hybridist, a breeder of hybrids.

Hybridization, the breeding of hybrids.

Hydra-polype (Gr. *hydor*, water, and polype), a fresh-water animal.

Id (p. 58).

Idant (p. 58).

Idioplasm (Gr. *idios*, one's own ; *plasma*, form) (p. 57).

Immunity, immune (L. *in*, not ; *munis*, serving), exemption from infection (p. 115).

Infusorian (L. *in*, into ; *fundere*, to pour), protozoa found in stagnant infusions of animal and vegetable matter.

Integral (L. *integer*, entire) (p. 78).

Intra-uterine (L. *intra*, within ; *uterus*, womb), within the womb.

In utero (L. *in*, in ; *uterus*, womb), in the womb.

Invertebrate (L. *in*, negative ; *vertebra*, the bone of the spine), without a backbone.

Karyokinesis (Gr. *karyon*, kernel ; *kinesis*, motion) (p. 30).

Katabolism (Gr. *katabolē*, a throwing down), the downward process of assimilation in the body.

Lamarckism, Lamarckian, the theory of Lamarck (p. 93).

Latent (L. *latere*, to lie hidden), dormant, not visible.

Linine (L. *linum*, flax) (p. 30).

Mammal, mammalian (L. *mamma*, breast), animals having breasts and suckling their young.

Maturation (L. *maturus*, ripe) (p. 36).

Mean (L. *medianus*, middle) (p. 150).

Median (L. *medianus*, middle) (p. 150).

Mendelism, Mendelian, the theory of Mendel (p. 120).

Mendelize, to conform to the Mendelian law (p. 140).

Mesoderm (Gr. *mesos*, middle ; *derma*, skin), the middle germinal layer of the embryo (p. 48).

Metabolism (Gr. *metabolē*, a change), the sum of the chemical changes within the living organism.

Metaphyta (Gr. *meta*, after ; *phyton*, plant), many-celled plants (p. 6).

Metazoa (Gr. *meta*, after ; *zōon*, animals), many-celled animals (p. 6).

Micrcsome (Gr. *mikros*, little ; *soma*, body) (p. 58).

Mid-parent (p. 162).

Mitosis (Gr. *mitos*, a thread) (p. 30).

Mnemic (Gr. *mnemē*, memory), pertaining to memory.

Mode (L. *modus*, rule), (p. 150).

Modification (L. *modus*, a measure ; *facere*, to make), changed condition.

Monœcious (Gr. *monos*, single ; *oikos*, house), having the two sex-organs upon the same individual (p. 22).

Monohybrid (Gr. *monos*, single, and hybrid) (p. 127).

Monotremata (Gr. *monos*, single ; *trema*, hole), the lowest order of mammals having a single external opening for the genital and digestive organs.

Morphological (Gr. *morphē*, form ; *logos*, discourse), pertaining to the science of form.

Morphoplasm (Gr. *morphē*, form ; *plasma*, form) (p. 57).

Morula (L. *morum*, mulberry) (p. 47).

Mucous (L. *mucus*, slime), slimy, pertaining to the internal lining of the mouth, etc., which secretes a slimy substance.

Multi-cellular (L. *multus*, many ; *cellula*, cell), many-celled.

Mutation (L. *mutare*, to change) (p. 140).

Myranida (Gr. *myrios*, numberless), a marine worm.

Neurosis, neurotic (Gr. *neuron*, a nerve), a nervous disease.

Nucleus (L. *nux*, nut), kernel (p. 5).

Nucleolus (L.), a small kernel (p. 30).

Ontogenesis, ontogenetic (Gr. *ōn, ont-*, being ; *genesis*, generation), the individual development of an organism.

Ovum (L.), egg.

Pangenesis, pangenetic (Gr. *pas, pan*, all; *genesis*, generation) (p. 54).

Panmixia (Gr. *pas, pan*, all; *mixis*, mixture) (p. 100).

Parthenogenesis, parthenogenetic (Gr. *parthenos*, virgin; *genesis*, generation), virgin-birth (p. 24).

Particulate (L. *particula*, a small part), pertaining to small parts.

Pathological (Gr. *pathos*, suffering; *logos*, discourse), pertaining to disease.

Phthisical (Gr. *phthiein*, to waste away), pertaining to phthisis, the wasting disease (consumption).

Phyletic (Gr. *phylon*, race), pertaining to the race.

Pistil (L. *pistillum*, a pestle), female sex-organ of the flower.

Planarian (L. *planarius*, flat), lowest class of worm-like animals.

Polarity (L. *polus*, pole), state of having two opposite poles with powers in opposite directions.

Polype (Gr. *polys*, many; *pous, pod-*, foot), an animal like the fresh-water hydra.

Potentially (L. *potis*, able), existing in possibility.

Predisposition (L. *praedispositus*, prepared), a susceptibility.

Preferential (L. *prae*, before; *ferre*, to bear), having a preference.

Preformation (L. *prae*, before; *formare*, to form), antecedent formation.

Preponderant (L. *prae*, before; *pondus*, weight), outweighing.

Prepotent (L. *prae*, before; *potis*, powerful), predominant.

Progeny (L. *pro*, before; *genēs*, producing), that which is brought forth, descendants.

Pronucleus (L. *pro*, before; *nucleus*, kernel) (p. 43).

Protista (Gr. *protistos*, the very first), the lowest organisms (p. 6).

Protophyta (Gr. *protos*, first; *phyton*, plant), the lowest one-celled plants (p. 6).

Protoplasm (Gr. *protos*, first; *plasma*, form), the substance forming living matter.

Protozoa (Gr. *protos*, first; *zōon*, animal), the lowest one-celled animals (p. 6).

Quartile (L. *quartus*, fourth) (p. 152).

Recessive (L. *recessus*, a going back), receding (p. 121).

Regeneration (L. *re*, again; *generare*, to generate), renewal (p. 7).

Regression (L. *re*, back; *gradi*, to step), a going back (p. 161).

Reproduction (L. *re*, again; *producere*, to produce), the producing of new organisms (p. 10).

Reversion (L. *re*, back; *vertere*, turn), a turning back (p. 81).

Rotifer (L. *rota*, wheel; *ferre*, to bear), the wheel-animalcule, a minute aquatic animal.

Sea-anemone (Gr. *anemos*, wind), a kind of polype living in wind swept situations.

Sea-squirt, a marine animal.

Segmentation (L. *secare*, to cut), the act of cutting into parts.

Segregation (L. *se*, apart ; *grex*, flock), separation into like parts.

Seminal (L. *semen*, seed), pertaining to the seed.

Soma, somatic (Gr.), body.

Somatogenic (Gr. *soma*, body ; *genēs*, producing), arising in the body (p. 96).

Spermatophore (Gr. *sperma*, seed ; *pherein*, to bear), the case enclosing the spermatozoa in some invertebrates.

Spermatozoon (Gr. *sperma*, seed ; *zōon*, animal), the male sex-elements (p. 22).

Sporulation (Gr. *sporos*, seed), the act of producing spores.

Stamen (L. *stare*, stand), the male organs of the flower.

Stirp (L. *stirp*, root) (p. 56).

Telegony (Gr. *telē*, distance ; *gonos*, seed) (p. 86) .

Testes (L. *testis*), the male sex-gland.

Triton (Gr., a Greek marine god), a kind of newt.

Trophoplasm (Gr. *trophē*, nourishment ; *plasma*, form) (p. 57).

Tunicata (L. *tunica*, a tunic), a class of animals covered with integuments, as sea-squirts, etc.

Type (Gr. *typtein*, to strike) (p. 154).

Unicellular (L. *unus*, one ; *cellula*, cell), one-celled.

Unilateral (L. *unus*, one ; *latus*, side), one-sided.

Vertebrata, vertebral (L. *vertebra*, a bone of the spine), back-boned animals.

Vesicle (L. *vesica*), a bladder.

Volvocineæ (L. *volvere*, to roll), an order of fresh-water algæ.

Volvox (L. *volvere*, to roll), a small genus of fresh-water algæ.

Vorticella (L. *vortex*, a whirl), a kind of infusorian.

Xenia (Gr. *xenos*, guest) (p. 87).

Zygote (Gr. *zygon*, yoke) (p. 124).

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