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*THE PROBLEM OF DEVELOPMENT.**

THE selection of such a subject as the problem of development for a general address to this academy as a whole suggests a word of explanation. Within the privacy of our sectional meetings we are permitted to dig and delve as much as we please among the dry bones of specialization; but on this occasion a righteous tradition imposes upon the president the duty of laying aside his special tools in order to address the whole scientific body over which he has for a time had the honor to preside. In offering a brief general dis-

* Annual address of the president, New York Academy of Sciences, December 19, 1904. The critical reader will, I hope, be willing to bear in mind the conditions under which this address was delivered. My endeavor was to convey to a scientific body, composed only in part of biologists, some individual impressions of a student of embryology and cytology regarding the general bearings of recent researches in his special field. It was not consistent with this purpose to give a critical résumé for biologists, nor could authorities be cited in detail. The general conception here developed will recall certain views contained in Driesch's 'Analytische Theorie der organischen Entwicklung,' published in 1894 (themselves traceable to earlier conclusions of de Vries), but afterwards rejected by him in favor of an explicit theory of vitalism. The rediscovery of Mendelian inheritance, the newly produced evidence, on the one hand, of morphological and physiological diversity among the chromosomes; on the other, of protoplasmic prelocalization in the egg, have, however, placed the whole problem in a new light. I wish to acknowledge my indebtedness to Professor Whitman's fine essays on the questions that center in Bonnet's doctrines, published in the 'Wood's Hole Biological Lectures,' for 1893, which suggested the quotation from Huxley.

cussion of some latter day problems of embryology and cytology I shall endeavor not to violate the spirit of this tradition. The task is not an easy one, owing to the complexity of the data and their strangeness to those who have not closely followed the details of modern biological work; yet I am encouraged to make the attempt by the belief that the problem of development belongs to those larger scientific questions that are of enduring interest to all students of nature. It is only fair to point out, however, that a consideration of recent advances in this subject necessarily and speedily leads us into a region that lies remote from everyday experience, surrounded by arid wastes of technical detail, and inhabited by folk who speak an uncouth foreign tongue. With the best of intentions, therefore, the native guide and interpreter has need of some forbearance on the part both of his countrymen and of the outlanders whom he attempts to lead.

I need not dwell on the absorbing, almost tantalizing, interest with which the problem of development has held the attention of naturalists from the earliest times. Twenty centuries and more have passed since Aristotle first endeavored to trace something like a rough outline of its solution. The enormous advances of our knowledge during this long period have taken away nothing of the interest or freshness of the problem; they have left it, indeed, hardly less mysterious than when the father of science wrote the first treatise on generation. I will not dwell on the epoch-making work of Harvey, Wolff and von Baer, or the curious, almost grotesque controversies of the eighteenth century, when embryology invaded the field of philosophy and even of theology. I will only point out that even at that time, when embryology was almost wholly limited to the study of the hen's egg, embryologists were already occupied with two fundamental questions, which still remain in their essence without adequate answer, and though metamorphosed by the refinements of more modern observation and experiment still stand in the foreground of scientific discussion. The first of these is the question of preformation *versus* epigenesis—whether the embryo exists preformed or predelineated in the egg from the beginning or whether it is formed anew, step by step, in each generation. The second question is that of mechanism *versus* vitalism—whether development is capable of a mechanical or physico-chemical explanation, or whether it involves specific vital factors that are without analogy in the non-living world. It is especially to some modern aspects of these two questions that I invite your attention; and I shall also consider briefly their relation to recent conclusions affecting our theories of heredity and evolution.

Let us first seek to define more clearly the meaning of our terms. The embryologists of the pre-Darwinian period, unhampered by historical conundrums, fixed their attention on the single objective problem of the nature of the germ and its mode of development. The hen's egg contains something which, though not visibly a bird or even an embryo, will when maintained at a temperature of about 37° C. for 21 days cause a living chick to step forth from the shell. What is that something and what manner of machinery (if machinery it be) is set in motion to work such a marvel? The early embryologists found no real answer to this question. They determined the fact that at the beginning the egg contains nothing even remotely resembling a bird; that as early as the second day a rudely fashioned embryo is visible in the egg; and that day by day, as the incubation proceeds, this embryo becomes more complex. The bird appears to be progressively created out of something that is without form and void of visible structure. Its development, said Harvey and Wolff, is essentially a process of 'epigenesis'—a successive formation and addition of new parts not previously existent as such in the egg. This conclusion, roughly outlined by Aristotle, was apparently established on an irrefragable basis of observation, long afterwards, by Harvey and Wolff. In its superficial aspects the doctrine of epigenesis is no more than a statement of universally admitted fact. When followed to its logical end, however, this conception has failed, and will always continue to fail, to satisfy the mind; and some of the most acute of modern embryologists have expressed the opinion that no thoroughgoing hypothesis of epigenesis can be so framed as to be logical, or even conceivable. Even in the eighteenth century this doctrine was met by the opposing one of preformation and evolution. Advocated by such men as Malpighi, Haller and Leibnitz, this conception underwent its fullest development in the hands of the eminent Swiss naturalist Bonnet. Developed with great logical acuteness and set forth with captivating literary skill, Bonnet's theory was based on the fundamental assumption that the embryo, though invisible, really exists preformed in the egg before development begins. The preformed germ was not conceived to be an exact miniature model of the adult. On the contrary, Bonnet thought of the germ of the fowl, for example, as differing widely in form and proportions from an actual bird, still the original preformation was assumed to be composed of parts that correspond, each for each, to the parts of the chick. Development, accordingly, was conceived to be only the unfolding and transformation of a preexisting structure, not the successive formation of new parts—a process of 'evolution,' not of epigenesis. In this particular form the doctrine of preformation was conclusively overthrown by Wolff; but the principle underlying it has repeatedly and persistently reappeared in later speculations on development, and still contests the field of discussion with its early antagonist.

Hand in hand with this controversy has gone one of still more general scope between the two opposing conceptions that I have referred to as mechanism and vitalism. Is development at bottom a mechanical process? Is the egg a kind of complex machine, wound up like a piece of clockwork, and does development go forward like the action of an automaton, an inevitable consequence of its mode of construction? Or, on the other hand, does development involve the operation of specific vital entelechies or powers that are without analogue in the automaton and are not inherent in any primary material configuration of the egg? This question, I hardly need say, is included in the larger one, whether the vital processes as a whole are or are not capable of mechanical explanation. As a problem of embryology it is very closely connected with that of preformation or epigenesis, and in point of fact the two have always been closely associated. Evidently, by its very form of statement, any theory of preformation or prelocalization in the germ assumes at least a mechanical basis for development, *i. e.*, a primary material configuration upon which the form of development in some measure depends. With theories of epigenesis the case is not so clear; for such theories may or may not be mechanical. Without further preamble I now ask your attention to certain facts which will place clearly before us the form in which these time-honored problems appear to us to-day.

It is a familiar fact that development begins with the progressive segmentation or division of the egg into cells, which, continually increasing in number, finally build up the body of the embryo. Until comparatively recently it was not suspected that the cells thus formed in the earliest stages had any constant and definite relation to the parts of the future body. The fact has how been established, however, that in a large number of forms (though apparently not in all) such a definite relation exists, both the form of division and the prospective values of the cells being constant. In the egg of the ascidian, for instance, the first cleavage-furrow passes pretty accurately through the future median plane of the body, and the two cells thus formed give rise respectively to the right and left sides of the embryo. In a snail's egg the relation is a different one, but is no less definite and constant; in the four-cell stage, for instance, the material that will produce the shell and foot is located, mainly at least, in one of the four

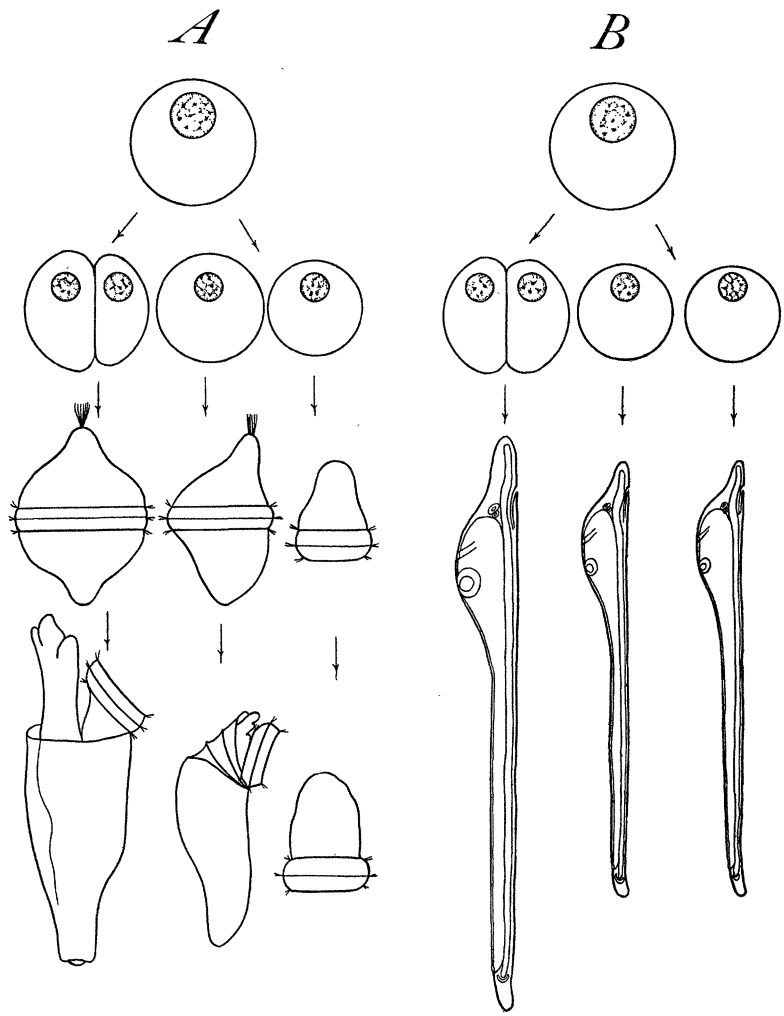

Fig. 1.—Development of entire eggs and of isolated blastomeres of two-cell stage. *A*, *Dentalium;* at the left, development of the whole egg; at the right, development of the isolated first two cells, producing two defective larvæ. *B*, *Amphioxus;* the corresponding experiment, isolated cells producing two perfect dwarfs.

cells. Again, in a worm's egg, after its segmentation into sixteen or more cells, we know very exactly how the materials for the head, the segmented trunk-region, the digestive tract, the muscles and the ganglia, are distributed among these cells. In all such cases the embryo seems comparable to a piece of mosaic-work, each cell apparently having its own inherent particular character, and its own specific rôle to play.

These facts place very conspicuously before us a modern form of the problem of preformation which we may conveniently call the problem of 'germinal *prelocalization.*' Does this mosaic-like character of the early embryo mean that the cells are inherently different? Are they in any degree individually predestined for their future development; and if such be the case, can this predestination be traced back to protoplasmic regions in the egg before it has divided into cells? In other words, does the egg, or does it not, contain prelocalized, predetermined areas that have any necessary or causal relation to the parts of the future embryo? This is the first guise in which the old question of preformation presents itself to us to-day. I ask you to glance at the results of a few very simple experiments designed to test this question. They will give apparently quite contradictory results.

Experiments on the eggs of certain animals, such as ctenophores or mollusks, seem to give an unequivocal answer to our questions. If, for example, the cells of the segmenting egg of the mollusk *Dentalium* or *Patella* be separated from one another, at the two-cell stage or any later period, they continue to develop and produce living, actively swimming structures; but these creatures are not completely formed whole embryos, but monsters that in many respects resemble pieces of a single embryo (Fig. 1, *A*). It is true that the wounds usually close and heal; but these structures, nevertheless, remain monstrous and defective, and if they are carefully studied it is found that only when taken collectively can they be said to constitute a single whole embryo. The cells are thus proved to be in some measure inherently different, and to this extent the cell-mosaic is shown to be a real mosaic. If we now extend our operation to the undivided egg, a result in harmony with this is reached. If certain portions of the egg of *Dentalium* be artificially cut off, the remaining portion, upon fertilization, regularly gives rise to a defective and monstrous creature that is not a whole embryo, but resembles a piece or fragment of an embryo. It is evident that this experiment seems to show pretty clearly that even before the egg has begun to divide into cells the parts of the future embryo are in some measure definitely prelocalized and predetermined in its different protoplasmic regions; and evidently, if this be the case, we seem further to have good ground for the mechanistic assumption that the undivided egg contains some kind of structural or material configuration upon which the character of the development depends.

But let us not on this account too hastily accept a theory of preformation or prelocalization. Let us first look at the results of an exactly similar experiment performed on the egg of certain other species of animals, for example, *Amphioxus,* a sea-urchin, or a nemertine worm. Separate here the first two or four cells, and each develops, not into an abortive monster, but into a perfectly formed though dwarf larva (Fig. 1, *B*). Thus it is possible to produce from a single egg from one to four perfect animals; and in case of certain species (hydromedusæ) it is theoretically possible by a similar method to produce from a single egg as many as eight or even sixteen perfect dwarfs. Again, in some of these cases, for instance in the nemertine, the undivided egg may be cut to pieces in any planes taken at random; yet every piece, if of sufficient size, may upon fertilization develop as if it were a whole egg and produce a perfect dwarf. Here is an astounding contrast to the results of our first experiment. What becomes of our theories of prelocalization here, and what becomes of our mechanical theory of development, if we hold such a theory? Neither the cells nor the regions of the egg seem to have any predestination such as is shown in the molluscan egg. It is the essence of a machine or automaton that its operation is due to its structural configuration. Impair or destroy that configuration and the action ceases. But from these eggs we may take away any of the parts, or the

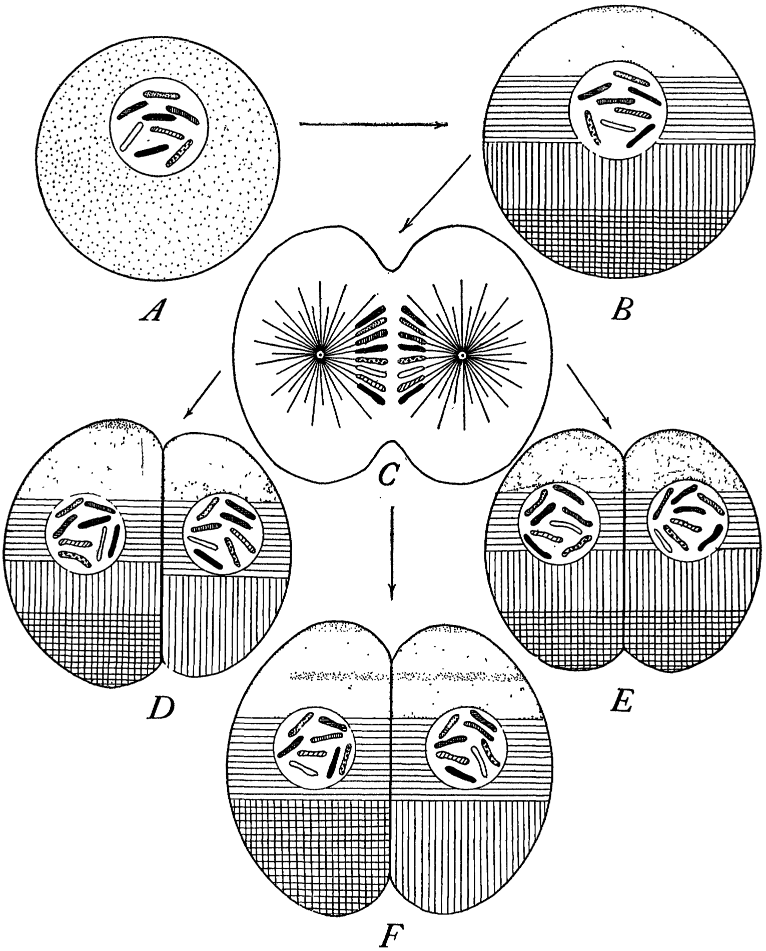

Fig. 2.—Diagram of protoplasmic zones and their distribution at the first cleavage in different forms. *A*, immature egg, assumed to have no definite segregation of protoplasmic stuffs. *B*, mature egg, with protoplasmic zones of horizontal stratification. *C*, first cleavage, division of the chromosomes. *D*, *E*, *F*, different types of two-cell stage. *D*, Dentalium type, the lower zone isolated in one cell. *E*, *Amphioxus*, nemertine, or echinoderm type; equal division of the zones. *F*, hypothetical type with complete separation of two zones at the first cleavage.

whole may be cut to pieces, yet there is no impairment of action, but only a readjustment to form smaller systems like the original whole. The egg, therefore, says the vitalist, can not be an automaton and its development is inexplicable upon a mechanical theory.

Such is the paradoxical result to which a superficial comparison of these two cases leads us—a kind of embryological antinomy, as it were, which at first sight may seem to take away all hope of finding law or order in these phenomena. I will undertake to show you speedily that the apparent contradiction is easily explicable. I have placed the two cases side by side because each seems to demonstrate the truth of one side of an ancient embryological controversy; and we shall presently find reason for the conclusion that each of the opponents, like the two knights and the shield, have recognized but a part of the truth.

The probable explanation of the difference of the behavior between the eggs of *Dentalium* and of *Amphioxus* is a very simple one. When we closely study eggs of this type we find that they do not consist of homogeneous protoplasm, but of different kinds of protoplasmic materials or stuffs that are at the outset arranged, roughly speaking, in horizontal bands or strata, as indicated in the diagram (Fig. 2, *B*), where the number of strata is arbitrarily assumed to be four. Now, an examination of the manner in which the egg divides gives strong reason for the conclusion that in such forms as *Amphioxus* the first division bisects these stuffs, so that each of the first two cells receives one half of each stratum (Fig. 2, *C, E*). In the egg of *Dentalium,* on the other hand, this is demonstrably not the case, for the lower stratum passes over bodily into one of the cells and is quite excluded from the other (Fig. 2, *D*). The symmetrical division in *Amphioxus,* the sea-urchin, or the nemertine, gives the immediate possibility of producing two smaller systems similar to each other and to the whole egg. The symmetrical or qualitative division in *Dentalium,* on the other hand, does not give such an immediate possibility, for it produces two different systems neither of which is identical with that of the entire egg. It is highly probable that we find here a proximate explanation of the fact that each of the two cells in *Amphioxus* may produce a perfect dwarf, while in *Dentalium* neither produces such a larva. Facts like these are leading us to the conclusion that the immediate determining causes of development are to be sought in specific protoplasmic stuffs, or organ-forming materials, that are distributed to the cells in a definite way during division. These materials, definitely arranged, are sometimes plainly visible in the undivided egg. I have, for instance, been able to show that the egg of *Dentalium* contains an area of protoplasm at the lower pole that has a causal connection with the formation of the foot and shell, and probably also of the principal part of the mesoblast structures; for if this area be cut off from the unsegmented egg the resulting embryo regularly lacks these structures. In like manner, Professor Conklin has recently been able to recognize in the protoplasm of the unsegmented egg of a species of ascidian the material of the future tail-muscles of the larva; and though no necessary connection between this material and the muscles has thus far been experimentally proved, my experiments on *Dentalium* leave by analogy little doubt that such a causal connection exists. We do not in the least know how these protoplasmic stuffs or materials act. We can hardly imagine how it is that one kind of stuff involves the development of muscles, others that of nerves, ciliated cells, or shell-secreting cells. We may guess that these stuffs may be analogous to the so-called internal secretions, formed in the adult organism by such organs as the thyroid or the sexual glands, which are known to produce quite specific morphological effects on the body. A second guess is that the formative stuffs may be related to the soluble ferments or enzymes, which in other ways play so great a rôle in the economy of plants and animals.

But, aside from this question, the evidence is steadily increasing, I think, that such stuffs exist, that they have a definite arrangement in the egg, and that in cases where the form of cleavage is constant they are distributed in a definite way to the cells into which the egg splits up. The cleavage-mosaic is accordingly to be conceived as an actual mosaic of different materials that are somehow causally connected with the development of particular parts. When these materials are equally distributed by the earlier divisions, as in *Amphioxus,* each of the resulting cells may upon isolation produce a perfect larva; when they are unequally distributed, as in *Dentalium,* the cells are no longer equivalent, and upon being isolated produce the structures corresponding to the particular stuffs allotted to them.* These facts will presently bring us to our first general conclusion. First, if the protoplasm contain such stuffs, grouped and distributed in a definite way, to just this extent may development receive a mechanical interpretation—that is, be conceived as the result of an antecedent material configuration in the egg-protoplasm. We have as yet no very distinct idea regarding the degree of complexity of this initial protoplasmic configuration, though there are facts that indicate that it may not be very great, *i. e.,* that the prelocalization is of a somewhat general character. This question appears, however, to be of relatively minor importance in view of an additional conclusion given by detailed studies on the formation, maturation and early development of the egg. These studies leave no doubt that the grouping of materials observed at the time the egg begins its process of division is not, in some cases at least, a primary or original one, but is of secondary origin. They indicate further that early in the development the egg contains only a few of these specific stuffs, at the very beginning possibly none, and that as development goes forward new stuffs are progressively formed and distributed. Now, if this conclusion is well founded, the actual progressive development of the protoplasm must be conceived as a process of *epigenesis,* not of preformation and evolution. This is the first general result that I desire to emphasize; and it is in harmony with the fact, on which all embryologists have been agreed, since the time of Wolff, that in its obvous features development is by the formation and addition of new parts not previously existent as such in the egg. The embryo is not actually preformed or even predelineated in the protoplasm from the beginning. The protoplasmic stuffs appear to be only the immediate means or efficient causes of differentiation; and we have still to seek its primary determination in causes that lie more deeply. We are thus led to a brief consideration of the question of the physical basis of heredity, which will direct our attention to an element that has hitherto been disregarded, namely, the nucleus, and bring us to a second general result.

It was long since suggested by Nägeli

* It will appear in the sequel that even in the latter case the potentiality of producing a complete embryo may still be present in the nucleus. It is important to distinguish between such primary or original nuclear potentiality, which may be common to all the cells, and the secondary or immediate potentiality determined by protoplasmic specification. The relation between these is still an unsolved problem.

that there is a particular substance or 'idioplasm' peculiar to each species of plant or animal that is transmitted in the germ-cells and has the power to determine the development of the egg according to its nature. Later research has given very strong reason to accept this view in principle, and for the further conclusion that this physical basis is represented by a substance contained within the nucleus and known to cytologists as 'chromatin.' Passing over the cogent, and I believe steadily accumulating, evidence on which this conclusion rests, let us ask how the idioplasm is to be conceived. Some of those who have accepted the general conception of the idioplasm have endeavored to think of it as a very complex but still single and homogeneous substance—the frog's egg, for example, might be conceived as containing a frog-determining substance, the human germ a man-determining substance, and so on. The most recent researches are, however, continually strengthening the ground for a quite different conception, indicating that the chromatin does not operate as a simple substance, but is built into a complex fabric having a definite architecture. We are not here concerned with the particular form of this conception developed by Weismann in his well-known work on the *Germ-plasm,* and elsewhere. I am referring to more recent results of observation and experiment which are giving new and more concrete evidence that the nucleus possesses a complex organization, and apparently one that must be conceived as a kind of primary or original preformation, which bears a certain analogy to that assumed by Bonnet, though quite distinct from it.

We may perhaps most readily approach the grounds for this conclusion by considering, first, an example of the indirect evidence drawn from recent experiments on inheritance. I give a single example, typical of a large number of known cases, of the heredity of single or unit characters in the so-called Mendelian inheritance. If pure gray mice be crossed with pure white albino forms, the hybrid offspring are all gray without visible trace of white. But if these gray hybrids be now paired with each other, both parents being gray, approximately 25 per cent. of their progeny are pure white without a trace of gray, and they continue to produce pure white offspring thereafter. Many similar cases are known, the same proportion of approximately 25 per cent. of the 'recessive' character in the third generation holding true, sometimes with great precision. What does this prove? First, that the white character is not really absent in the gray hybrids but only masked or concealed—'recessive,' in Mendel's terminology; secondly, that the latent white character may in the following generation be completely disentangled or extracted from the gray; thirdly, since the proportion is definite, that the extraction takes place by means of some definite mechanism. We are at present, I think, unable to imagine an explanation of these truly astonishing facts save by the assumption that the gray and white characters are borne in the egg by corresponding discrete bodies or entities of some kind, that may be mixed and unmixed without fusion, shuffled and unshuffled like cards in a pack. The evidence is so far wholly indirect, though I think none the less cogent. But now, bearing in mind that the case of the gray and white mice is but a single example of a widespread phenomenon, let us ask whether we can actually find any definite structures in the egg, and particularly in the nucleus, that may be assumed to represent such entities. One of the most significant and remarkable discoveries of modern biology is the fact that such entities exist, though it is important not to forget that their significance in heredity is

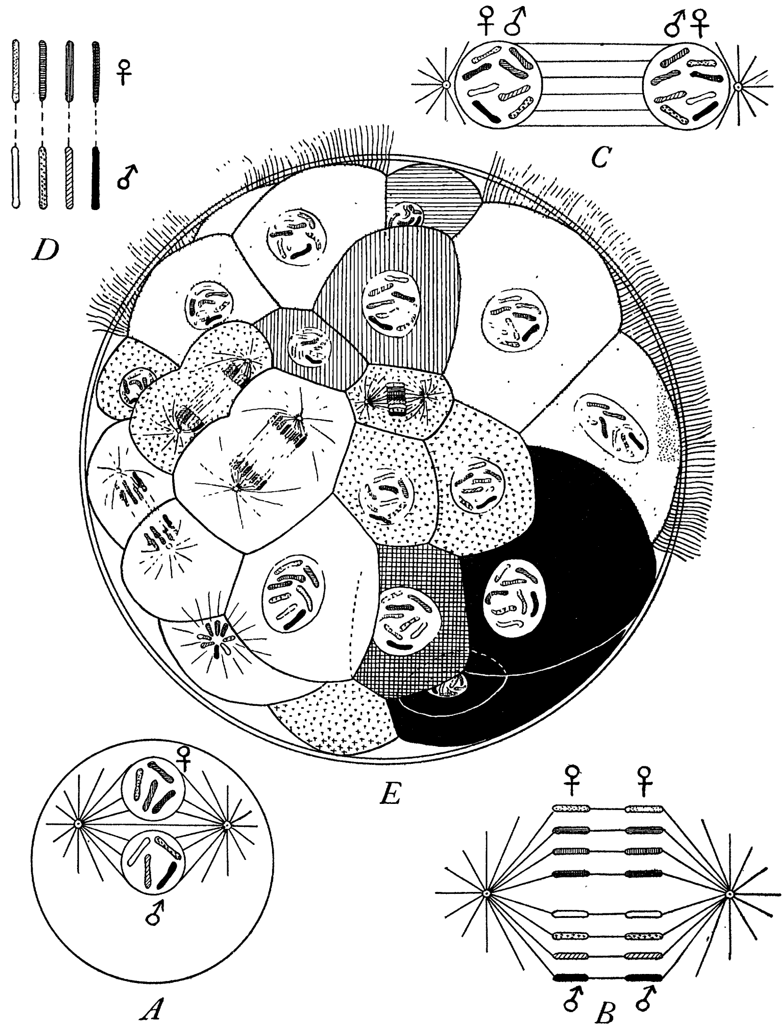

Fig. 3.—Relations of the chromosomes; formation and distribution of protoplasmic stuffs in later stages. *A*, union of the germ nuclei (each assumed to have four chromosomes). *B*, *C*, division of the chromosomes, with equal distribution of the paternal (♂) and maternal (♀) products. *D*, scheme of nucleus at any later stage, with four paternal and four maternal chromosomes (corresponding or homologous chromosomes connected by dotted lines). *E*, actual outline (after Mead) of egg of *Amphitrite* consisting of upwards of 64 cells (nuclei schematized). Entoblast-cells unshaded, primary mesoblast cross-hatched, trochoblasts (ciliated cells) dotted, cells of ventral plate (ventral nervous system, etc.) black; the other cells belong to the ectoblast.

as yet only an assumption, not a completely demonstrated fact.

These entities are bodies known as 'chromosomes,' and are represented in the diagrams by the rods in the nuclei.* I can not within the limits of this address attempt to do more than touch on a few of the discoveries of recent years regarding the chromosomes, though I think they may

* In point of fact the chromosomes are, as a rule, only distinctly visible at the period of cell-division. In the diagram they are represented quite schematically, as if visible in the resting nuclei.

fairly be claimed to constitute one of the most brilliant chapters in the whole history of biology. The number of the chromosomes is constant in each species and, with only a few exceptions of such a kind as to emphasize the rule, the number in sexually produced organisms is always an even one. It has been proved that during the fertilization of the egg one half of the chromosomes are derived from the father and one half from the mother (Fig. 3, *A*), and the still more suggestive fact has been established—with probability through the study of normal development, with almost complete demonstration through the study of hybrids—that at every division of the egg the chromosomes also divide (Figs. 2, *C*, 3, *B*, *C*) in such a manner that their progeny are distributed in equal number, step by step, to all the cells of the body. The remarkable conclusion is thus reached that the fertilized egg, and all the cells derived from it, contain a double set of chromosomes, paternal and maternal (Fig. 3, *D*). The no less interesting result has been experimentally reached that either set—paternal or maternal—is sufficient for complete development (at least as far as the larval stages); for the egg may be caused to develop without the paternal chromosomes, while conversely the paternal chromosomes alone will suffice for the development of an egg from which the maternal nucleus has been removed. Here for the first time we catch a glimpse of the probable physical explanation of the phenomena of dominance and recession that have of late so greatly aroused the interest of experimenters on inheritance; but above all, here is found our first definite basis of observation for the assumption that the nuclear organization is not merely a chemical or molecular one, but represents beyond this some kind of definite material configuration of the nuclear substance.

The time will not allow me to do more than touch on the very recent work that has confirmed and extended this conclusion. It has been found, first, that in some species the chromosomes show constant differences of shape and size, which points towards the conclusion that they may possess specific individual characters. But beyond this indirect evidence, and quite independently of it, Boveri has shown by direct experiments of great ingenuity and beauty that qualitative physiological differences among the chromosomes actually exist; for complete development is only possible in the presence of a particular combination of chromosomes. Hence the conclusion becomes probable that there is a definite causal relation of some kind between the individual chromosomes and the development of corresponding characters or groups of characters; or, in other words, that the hereditary characters are in some manner distributed among the chromosomes which form their physical basis in the egg. We do not yet know in precisely what form this conclusion should be formulated. We do not know, for instance, whether a single unit-character, such as color, is determined by a single chromosome, or by a combination of chromosomes, or whether this may vary in different cases. In this direction we have taken but the first uncertain steps towards a new horizon of discovery. But the point I wish to emphasize is that if we admit such a distribution of characters among the chromosomes in any measure and in any form, to just this extent have we admitted the principle of preformation as applied to the nuclear substance or idioplasm. To this extent do we admit, for example, that the physical basis of inheritance in a frog's egg is not simply a frog-determining *substance*, but is, in close analogy with Bonnet's conception, a kind of original preformation or microcosm, in which the individual frog-characters are in some unknown manner represented by corresponding chromosome-characters. We can hardly imagine at present how this is possible; and it must be freely admitted that such a conclusion has an appearance of artificiality and crudeness that almost inevitably creates a certain feeling of scepticism. Nevertheless, to a conclusion similar in principle to this the facts seem to be pretty definitely pointing.

And now, finally, let us see how this conception, if accepted, is to be united with that of specific protoplasmic stuffs, as already outlined. We do not know in any positive way, but we may roughly present the facts to our minds by a kind of artificial hypothesis—somewhat as Ehrlich and his followers endeavor to present the side-chain theory of immunity by means of rough and crude diagrams. Let us assume, for example, that the specific protoplasmic stuffs are formed one after another by means of substances like enzymes that emanate from corresponding chromosomes.* Putting the matter in the sharpest and crudest way, let us assume that each of the chromosomes in our diagram is responsible for the formation of the stuff correspondingly shaded. A few of these stuffs, formed and distributed as the egg ripens, determine the initial stages of development. In later stages other stuffs are formed by other chromosomes and progressively distributed to the cells by division. Thus the cleavage-mosaic grows progressively more complex and definite as development advances. Each nucleus still contains the germ or potentiality of the whole organism, but the cells assume specific characters according to the protoplasmic stuffs allotted to them (Fig. 3, *E*).

This attempt to portray briefly the *modus operandi* of development is doubtless an excessively naïve mode of formulating a highly complex and subtle process, concerning the real nature of which we still know very little. Even if literally correct it would still leave quite out of account some of the most important elements of our problem. I do not offer it as a well-established or fully rounded conclusion, but rather as a convenient way of placing before you one fundamental result, towards which I believe the drift of recent research is tending. This is that the germ consists of two elements, one of which undergoes a development that is essentially epigenetic, while the other represents an original controlling and determining element. The first is represented by the protoplasm of the egg. The second is the nucleus, which, as I have attempted to show, must apparently be conceived as a kind of microcosm or original preformation, consisting of elements which correspond, each for each, to particular parts or characters of the future organism. The actual development of the embryo, which is manifested by progressive changes in the protoplasm, is by epigenesis, as Harvey and Wolff maintained. Its primary determination is by means of a preformed apparatus, handed on to the egg from preceding generations in the nucleus, which, though not in any sense a miniature model of the adult, yet somehow embodies in infinitesimal compass, the heritage of the race. And thus the most recent discoveries in this difficult field of research are bringing us to a position which can hardly be better stated than in the words written by Huxley more than thirty years ago: "The process which in its superficial aspect is epigenesis appears in essence to be evolution, * * * and development is merely the expansion of a potential organism or original preformation according to fixed laws." We should not, with the advantage of our present standpoint, read into these words of Huxley's a meaning which it was impossible

* *Cf.* Driesch's 'Ferment-Fiktion,' Analyt. Theorie, pp. 87–92.

that he should have had in mind in writing them; yet without yielding to this temptation we may fairly pay our humble tribute of admiration and homage to a scientific insight that was capable of reaching such a conclusion in the far away prehistoric period when chromosomes and Mendelism were unsuspected, when the nature of fertilization was unknown, and the internal mechanism of development was a wholly unsolved riddle.

I will in conclusion add only a few words on the question of vitalism and mechanism in the light of the foregoing results. In so far as development may be conceived as the outcome of an original material configuration in the nucleus, and a secondary configuration in the protoplasm, it may be conceived as a mechanical process. But it must be admitted that this conception leaves quite unsolved certain fundamental elements of our problem—such, for instance, as the manner and order in which the protoplasmic stuffs are formed and assume their characteristic configuration, whether in the whole egg or in the isolated blastomere or egg-fragment; or again, how the wonderful phenomena of the regeneration of lost parts in the adult organism can be explained. We have at present no positive data for an answer to these questions. But it can hardly be disputed that we have already made a considerable advance towards a mechanical solution of the problem, and if this be so, by what right does the vitalist demand that we shall adopt his hypothesis for the portions still unsolved? Let us seek an answer to this question in the answer to a broader one. What is the object of the study of development? I should state this object somewhat as follows: First, to observe and to describe as completely and simply as possible the actual phenomena of development; secondly, to determine to what extent, from its beginning in the egg to its completion in the adult organism, the process can be formulated in terms of the elementary laws of matter and of motion. But this is only a different way of stating that our object is to ascertain in what measure the operations of development, under given external conditions, are the result of an original configuration of material particles in the egg. Now, I do not need to say that even the approximate accomplishment of these aims is still very remote, their complete accomplishment impossible. I am fully in accord with the neo-vitalists in their assertion that the phenomena of development and of life generally have not yet been reduced to a mechanical basis, that they can not at present be fully described in physico-chemical terms. It is certain that living beings exhibit structures more complex than any existing in the inorganic world, and different from them in kind. It is possible, probable I believe, that living bodies may be the arena of specific energies that exist nowhere else in nature. I admit fully that the interpretation of development I have endeavored to outline does not exclude, but in some ways actually suggests, the existence of such energies. I should, therefore, even admit that the vitalists are wholly right in their contention that the vital processes are not at present explicable as the direct result of such energies as are observed in the non-living world. To prejudge this question would set up a dogmatic barrier to progress, not only in biology, but also in chemistry and physics. If this be vitalism there are probably many of us who must be enrolled as 'vitalists,' however doubtfully we may regard the honor of bearing such a title. But if the word 'vitalism' be used in any other sense than as a convenient phrase, an x by which to designate an unknown quantity, if it be taken in a positive sense to imply in the living organism any negation of the fundamental laws of matter and of motion, the existence of any distinctive entity, or principle that does not fall within the chain of physical causation or that contravenes the general laws of physics, then, I protest, to accept 'vitalism' as a principle of interpretation is deliberately to abandon the scientific method in biological study.

EDMUND B. WILSON.

THE AMERICAN PALEONTOLOGICAL SOCIETY. SECTION A—VERTEBRATA.

SECTION A of the American Paleontological Society held its third annual meeting in common with the other societies on December 27, 28 and 29, and greatly enjoyed the admirable arrangements made by the officers of the University of Pennsylvania, especially by Professor Conklin. The President, Professor Henry F. Osborn, presided. At the close of the meeting Professor W. B. Scott was elected president and Dr. Marcus S. Farr secretary, both of Princeton University.

The meeting included a series of eighteen papers presented in person or in manuscript by Messrs. Osborn, Eastman, Sinclair, Case, Lull, Patten, Brown, Gidley, Hay, Loomis, Farr, Scott, Petersen, Douglass, Williston, Matthew and Granger. These were presented on Tuesday afternoon and on Wednesday and Thursday mornings. On Wednesday forenoon the president delivered his annual address, entitled 'Ten Years' Progress in Mammalian Paleontology.' In this address, which will be printed in full elsewhere, the history of the science during the last decade was followed in detail, and the principal advances, in the discovery of new forms, principles, and methods of work, were outlined. On Thursday morning the principal feature was the discussion of the phylogeny and classification of the Reptilia, in which Messrs. Osborn, Williston, McGregor and Hay participated. In this discussion Professor Osborn opened with a general review, pointing out the gradual development of the idea of a double grouping of the reptiles, beginning with Baur's phylogeny published in 1889 and continued in the phylogenies and discussions of Cope, Smith Woodward, Broom, Nopcsa, Williston, Boulenger, Osborn and McGregor. The following table is that of Osborn, 1904.

The chief differences of opinion at present relate to the position of the Ichthyosauria, Sauropterygia and Testudinata, some authors placing the Ichthyosauria as intermediate between the two groups, others placing them frankly with the descendants of the rhynchocephaloid reptiles, as suggested by Baur. Boulenger derives both the Sauropterygia and the Testudinata from the rhynchocephaloid, or diapsidan, group; whereas all other authors take them off from the synapsidan group.

Professor Williston continued the discussion, speaking especially of the Sauropterygia. He first stated that he considered the Sauropterygia and Testudinata as fundamentally separate groups, all their points of likeness being due to analogous evolution, while their points of difference are fundamentally distinctive. He considered the Triassic plesiosaurs Nothosaurus and Lariosaurus, as not ancestral to the Jurassic and Cretaceous plesiosaurs, but as representing an independent offshoot. He maintained that the Proganosauria, represented by the Permian genera *Mesosaurus* and *Stereosternum,* were certainly not ancestral to the plesiosaurs, as held by Seeley and Boulenger. The Testudinata are also widely separated from the Placodontia, and are probably of direct Cotylosaurian origin. The points of convergence are partly correlated with the large size of the paddles of plesiosaurs and turtles, the short tail being correlated with the long propodials in the plesiosaurs, whereas in the