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A DYNAMICAL HYPOTHESIS OF INHERITANCE (II.).

THE egg cannot be isotropic—as follows from observation as well as experiment—in the sense in which the word isotropy is used by physicists of repute. If the egg is a dynamical system it cannot be isotropic or absolutely the same throughout, or along every possible radius from its center, as is proved by its reactions in respect to its surroundings. It may, however, be potentially æolotropic in directions parallel to a certain axis, as experiment has shown by separating the cells that result from segmentation of the egg. Such fragments, if in excess of a certain minimal size, will undergo a larval development of apparently normal character. But this result is fatal to the ordinary corpuscular hypotheses, according to which every future part is represented in the chromosomes by certain hypothetical corpuscular germs. It has, indeed, been shown by Loeb that larval development of portions of an egg can go on whether the divisions be equal or unequal or in any radius. This seems to indicate that an egg is not necessarily isotropic in the undivided state, but that the moment that separation of its mass has occurred there is a readjustment of the relations and potentialities of its molecules simulating that of the original entire egg. The very definition of isotropy, as given by one author (Lord Kelvin), states that it may be assumed only of a spherical mass of matter whose properties are absolutely the same along every one of the infinite number of radii drawn from its center outward, and, as tested by any means whatsoever, shows that such a condition cannot be assumed, on the ground of observation alone, of any known egg. The condition of the egg we must therefore also assume from its known properties to be æolotropic, or different along every one of the infinite number of radii drawn from its center. When we make this assumption, however, we need not necessarily assume that nucleated fragments that will still develop into larvæ after division of the oösperm, natural or artificial, must be isotropic. They may be æolotropic from the beginning, but in precisely the same way in each case, as a result of the successive cleavages of the germ-mass, by means of planes that cut each other at right angles, as in the diagram Fig. 1, where each of the four segments are precisely alike from the pole *a* to that of *b*.

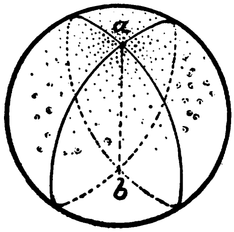

FIG. 1.

The unlikeness of the pole *a* from *b* is indicated by the stippling. This unlikeness would manifestly be unimpaired by segmentation of the germ into four quadrants by the first two cleavages, as shown in the diagram. The same might hold of octants of the spherical germ. Here the initial æolotropy of the whole egg determines that of its segments; that must therefore become four or eight molecular mechanisms, each with precisely the same type of potentiality as that of the whole egg. (See concluding note.)

There may, according to the foregoing view, be such a thing as perfect isotropy in every radius lying in a plane cutting the line from *a* to *b* at right angles. This would not, however, be the perfect isotropy of our definition that we are compelled to accept in the form in which it comes to us from the physicist.

As development proceeds, moreover, we have reason to believe that this æolotropy becomes more and more marked, so that eventually the huge metameric molecules become arranged in definite linear, parallel systems, as in the axis cylinders of nerve cells and in muscular tissue. Here the characteristics of the system become the the same in parallel lines, and in any directions at right angles to an axis parallel to these parallel lines of molecules. That is, in certain rectangular directions there is an approximation toward homogeneity. But the completest homogeneity is found to occur in only one direction in parallel lines extending through the mass. This condition we may designate as monotropy. Starting with the extreme æolotropic condition of the germ, we must, therefore, assume that as organization becomes more and more complete, in the progress of development, in the specialized systems of tissues and organs, the molecules become more and more definitely monotropic. Therefore they at last become incapable, as dynamical systems, of exhibiting a complex development such as is manifested by a germ, but capable only of manifesting the special physiological functions entailed by their dynamically and mechanically evolved monotropism.

We can now understand why it is that the germinal matter of a species always remains in an æolotropic state. Since germinal matter is always relieved of specialized functions in the body of the parent, it must perforce remain in its primitive condition of germinal potentiality as a molecular mechanism. Since the germ is material that has been produced in excess of the needs of metabolism of the parent body, as supposed by Haeckel and Spencer, it can do no work for that body. The unbroken continuity of the processes of metabolism has provided the conditions for the continuous or interrupted production of germinal matter.

The nearest approach to a condition of continuity of germinal matter is found in the tissue of the 'growing points' of plants, where, as in the banana, it has maintained its unabated vigor for probably not less than two thousand years without the help of sexual reproduction. In many organisms the germinal elements must grow and become mature. While in the immature state they do not, for the moment, have the latent potentiality of germs that can, then and there, develop, but may even be destroyed phagocytically, or absorbed by other non-germinal tissues. In still other cases there is no proof that the germinal matter is differentiated, as a complete mechanism, from the first stages of ontogeny onwards, so that the theory of its continuity is not only not always true but is also of small importance. At any rate, it is of far less importance than the fact of continuous metabolism and the gradual advent of monotropism, from a state of germinal æolotropism, effected by the dynamical process of tissue metamorphosis and specialization.

This development of monotropism cannot take place except through the sorting and grouping of specialized molecules, under the domination of forces, the operation of which remains to be discovered in the laws of physiological chemistry and molecular mechanics, and not by an appeal to an unworkable hypothesis that merely covers up our ignorance and impedes our progress by invoking the help of 'gemmules' or 'biophors' that grow and divide like cells. There is no evidence that will enable us to conceive the growth of the molecules of living matter in this way, since we are now dealing with very complex metameric molecular bodies, the growth and disintegration of which is probably essentially similar to the growth and solution of crystals, during the process of metabolism, with this difference that growth and disintegration go on at the same time in living bodies. We do not even know the real nature of the chemical changes that go on in these molecules and determine their structure. That the forces that do determine this are of a chemical nature, operating under very peculiar conditions, we may be certain. The complexity of these bodies, and their complex relations to one another, give us all the mechanism we need in order to account for the phenomena of heredity.

One-half or one-quarter, or an uneven part of the oösperm (Loeb), will operate in the same way as the whole. If we accept the dynamical hypothesis here proposed we are relieved of going to the length of the absurdity of assuming that by dividing a germ we multiply its 'biophors' as many times by two as we have made divisions, or of postulating 'double' or 'quadruple determinants.' The arithmetical impossibility of multiplying by a process of division is, as we see in this case, too much for any non-dynamical corpuscular hypothesis. Where the division of the germ is unequal, as in some of Loeb's experiments, we should, on the basis of a preformation hypothesis, be compelled to suppose that the 'double determinants' were unequally divided.

Regeneration is also to be explained upon the basis of a dynamical theory, as well as polymorphism, alternation of generations, reversion, and so on. We find indeed that it is only the same kind of tissue that will regenerate the same sort after development has advanced a considerable way. Monotropism has been attained by each kind of tissue, and this prevents the production of anything else but the one sort, in each case, after tissue differentiation has proceeded a little way. Polymorphic or metagenetic forms are to be accounted for in the same way as constantly repeated ones. Like the latter they are produced by the operation of a molecular mechanism, the story of the transformation of which is not told off in a single generation, but in the course of several distinct ones. Sex itself is thus determined and must in some way depend upon subtle disturbances of the transformation of the molecular mechanism of the germ, the nature of which is still quite unknown to us.

Equally remarkable are the phenomena of heteromorphosis described by Loeb, whose experiments prove that some animals, like most vegetable organisms, may adjust the molecular machinery of their organization in any new direction whatever that may be arbitrarily chosen, so as to realize the continuance by growth of the same morphological result as that which characterized them normally. These experiments would at first thought seem to prove that some organisms were isotropic, but such a conclusion is exceedingly doubtful. It may be that such organisms are, as molecular mechanisms, when subjected to new geotropic and heliotropic conditions, capable of correspondingly new adjustments of their molecular mechanical structure. But this would not be proof of isotropy—only proof of the assumption of a new condition of æolotropy, adjusted in respect to a new axis of reference, that also coincides with some part of the earth's radius prolonged into space. This readjustment of the molecular mechanism may be effected in some way by gravity, as Loeb himself has suspected. It is certainly not due to the control of any lurking 'biophors,' since it is a purely mechanical readjustment of an ultramicroscopic structure to new conditions which cannot be effected in any other than a mechanical way.

The production of monstrosities also may be explained by a dynamical hypothesis, provided we assume that the forces of ontogeny must operate against the statical equilibrium of the parts of the germ at every step. Especially if we assume in addition, as is born out by facts, that the æolotropy and consequent recapitulative power of the germinal substance is most marked in certain regions of the embryo. These regions, if their molecular equilibrium be mechanically or otherwise disturbed by division during development, will assert their germinal potentiality and produce an embryo, the relations of which to that already formed alongside of it will be modified by the statical conditions of surface-tension afforded by the adjacent embryo or the underlying yoke, or by both combined. This is beautifully illustrated by a host of facts. Double toes must have so arisen, as is proved by the direct experiments of Barfurth, some of which I have repeated, as well as by what happens when the toes of an Axolotl are persistently nibbled off by another animal, when duplication may not only take place in the horizontal plane of the foot or hand, but also in the vertical one. In this way a number of supernumerary toes may be caused to arise from a single stump, provided the re-growth of the toe be so interfered with as to compel regeneration from two terminal regenerative surfaces instead of one. This must follow from the law demonstrated by Barfurth's experiments, namely, that the regeneration of an organ tends to occur uniformly over and in a direction normal to the regenerating surface. In this way it is possible to mechanically determine the direction in which a regenerated part shall be reproduced by merely making changes in the angular relations of the plane of the regenerating surface to that of the axis of the body, as indicated by the diagram in Fig. 2 of the regenerated tail of a tadpole. Here the line I indicates the plane along which the tail has been removed, upon which regeneration will restore the tail straight

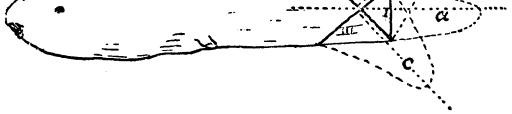

FIG. 2.

backward to the dotted area *a*. If the plane of section is along the line II the tail will regenerate upward so as to be restored over the area indicated by the dotted line enclosing *b*. If the plane of section of the tail be along III the tail will be regenerated downward to the dotted line enclosing the area *c*. It is therefore evident that Barfurth's law determines the inclination of the axis of the regenerated part to the body-axis, through the different conditions of surface tension that must be set up over regenerating surfaces, whenever the inclination of these to the axis of the whole organism is changed.

New equilibria of surface tension established reciprocally between the cohering but independently developing segments of the oösperm of the sea-urchin, that have been imperfectly separated by mechanical or other means, also cause changes to be produced in the forms of the single larvæ of such coherent groups, and in the spicular skeleton, for the same reason, as is proved by Figs. 23 to 25 given by Professor Loeb.* Those figures also illustrate the thesis that the æolotropy of the distinctly developing segments of the egg must be nearly the same, and that component or resultant equipotential surfaces are developed by the interacting molecular machinery of such coherently developing or compound larvæ.

The angular divergence of duplicated tails and toes as well as the axes of monstrous embryos is explained by Barfurth's discovery, taken together with the principle that division of a germ does not change the æolotropy of its segments. If this interpretation is the correct one, the origin of supernumerary digits must be traced back to mechanical disturbances of the processes of ontogeny. The rationale of the manner in which divergent supernumerary toes may be produced is shown in Fig. 3, representing the regenerating toes of the foot of a salamander.

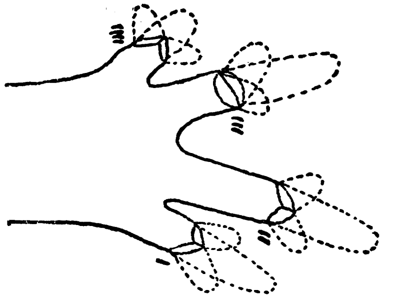

FIG. 3.

If the toes were cut straight across at the points I., II., III., IV., the toes would regenerate normally. If, however, the regenerating surfaces were divided into two areas in each case by a line along which regeneration were prevented, two toes would arise from each surface. The angular divergence of the pairs of supernumerary toes thus produced would be measured by the angular inclination to one another of the two areas at the end of each original toe that was thus doubly regenerated. In other words, supernumerary digits are the results directly or indirectly of something akin to mutilations. That such duplications may be produced by mutilations there can be no doubt, and of their transmission by inheritance to offspring there is also no doubt. These facts make it probable at any rate that regeneration of distal parts, and the likelihood with which they reappear in duplicate, is due to causes similar or identical in character with those that lead to the production of double monsters, by shaking, mutilation or other physical interference with the normal development of the oösperm. The question of the inheritance of mutilations is consequently far from being concluded as viewed from this new standpoint. Much evidence might be adduced in support of my contention did space allow. The hereditary transmission of such monstrosities as supernumerary digits

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is well known, and it is a singular fact that it is only the outer digits, *i. e.*, minimus and pollex, or hallux, or those most exposed to the liability of injury during development, that are, as a rule, duplicated. If the foregoing view is correct, the origin of supernumerary digits is not always to be ascribed to reversion. It must not be understood, however, that the theory is here defended that mutilations effected after adolescence is reached are likely to be transmitted.

The 'mutilations' here referred to are hardly to be regarded as such, but rather as the results of mechanical interference or disturbance of the statical equilibrium of those parts of the developing germ that are duplicated, as we see, in obedience to the principle discovered by Barfurth.

Another dynamical factor in development is so generally ignored that it must be especially referred to here. I now refer to the statical properties of the germinal substance in modifying development. Some of its effects we have already taken note of above. Karyokinesis has been shown by Hertwig to be dominated by the principle that the plane of division of a cell is always at right angles to its greatest dimension, a fact readily verified. The greatest dimension of the cell in turn is also often, if not usually, determined by the conditions of free and interfacial surface-tension manifested between the members of a cellular aggregate composing a segmenting egg. This appears to have a determining effect upon the plan of the cleavage. How far and in what way the remarkable movements of the centrosomes that occur during cleavage, and that have been most exhaustively studied by Professor E. G. Conklin, regulate segmentation still remains to be determined. There can, however, be but one explanation of such movements, and that must be a mechanical one, but its nature is entirely unknown. Wilson has shown that the conditions of free and interfacial surface-tension in Amphioxus vary in different eggs from some unexplained cause, so that the earlier cleavages of this form also vary to a corresponding and remarkable degree. In other cases surface-tensional forces operate under similar recurring conditions. In the fish-egg I have witnessed the reappearance of the same or similar interplay of statical energies thrice in succession, so as to produce three similar successive sets of formal changes in the egg that are traceable to the action of similar statical agencies. In *A*, Fig. 4, the germ *a* has assumed a lenticular form of statical equilibrium; after segmentation of the same disk has proceeded some way, as in *B*, the disk, as a cellular aggregate, has again assumed the lenticular form of equilibrium, while the outermost row of cells, *c*, are individually in a similar condition of equilibrium.

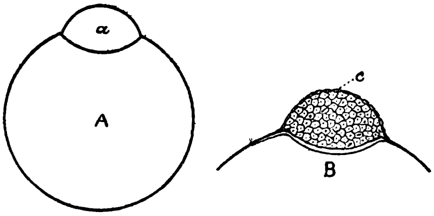

FIG. 4.

These facts are quite sufficient to establish the general truth of the statement that at no stage is the ontogeny of a species exempt from the modifying effect of the surface-tensions of its own plasma acting between the cells as if they were so much viscous dead matter. Such statical effects are not overcome at any stage of the development, or even during the life of any organism. On account of the universal presence and effect of this factor in both the plant and animal worlds, as a modifier of form, we are obliged to consider it as an agent of the first importance in the possible development of the future science of exact dynamical morphology. Its action is so constant an accompaniment of development that the forces of the latter may be divided into the kinetogenetic, or those that develop movement, and the statogenetic, or those that develop rest or equilibria, amongst the parts of the germ. The kinetogenetic forces are the consequences of metabolism, but the statogenetic forces, though dependent upon metabolism, are produced as a consequence rather of the interaction of the surface layers of the plasma of the cells, contemplated as if they were small cohering masses of viscous dead matter. These masses are separated, in the organism or germ, by interfacial planes, free and interfacial curved surfaces that are the results of segmentation and growth, and the extent of the areas of which obey a law first pointed out in relation to soap-bubbles by the blind physicist Plateau, who showed that such bubbles tended to form interfacial films and surfaces, wherever in contact with each other, of an area that was the minimal consistent with their statical equilibrium.* In this connection it may also be remarked that, inasmuch as the cells of a germ or organism are always in statical equilibrium, their surface layers of molecules also always represent complex systems of equipotential surfaces, no matter how intricate the form of the organism may be. Since the equilibria between the molecules of the surface layers of cells can normally be disturbed only by the metabolism incident to physiological activity, it is evident that the figure of the organism must ultimately be ascribed to the action of metabolism or to the functions of the organism as affecting the physical properties of its plasma.

A statical equilibrium in a living cell may be one in which it is not in contact with others at any point on its surface, as in the case of blood-corpuscles or disks. Or a cell may be greatly extended in one direction, as in the case of the axis-cylinder of a nerve-cell, owing to very unequal surface-tensions developed in one or more directions so as to draw it out into a condition of equilibrium, in assuming which it acquires a great length. Formal changes in cells, no matter how irregular these may become, must be due to alterations of surface-tension due to molecular transformations at certain points on the surface of globular or polyhedral embryonic cells. The final mature form of a cell is a consequence of the assumption of a statical equilibrium amongst its parts, due to the nature of its metabolism and its consequent molecular structure. The statogenetic factors of development are therefore of just as much importance as the kinetogenetic, or those involving motion. The statical forces that are developed in individual cells also act reciprocally between all of the cells of the organism, so that in this way the effect of statogeny extends throughout the entire organism.

If there were no such statical forces to be overridden by the purely kinetic ones developed by the molecular transformations and consequent motions incident to metabolism, provided the latter, together with assimilation, took place, during development, with great rapidity, the ontogeny of an organism would take place with such swiftness that it could not be successfully studied by embryologists. In other words, ontogeny would take place in the twinkling of an eye, and organisms as large as whales might even mature in an instant, provided the coefficients of viscosity and surface-tension of their plasma were to fall nearly to zero, while assimilation and metabolism proceeded with infinite rapidity.

It follows also from what has preceded that we can now form some idea why apparent rejuvenescence occurs in every on-

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* Some interesting applications of the geometrical theory of radical axes and centers also apply here that have never been studied in connection with the phenomena of segmentation.

togeny. Every germ must, for assignable reasons, begin its existence in the original, highly complex, æolotropic condition of the plasma of its species. It must therefore begin its career somewhat in the guise of the mechanically unspecialized plasma of a remote unicellular ancestor. Unlike that ancestor, however, the cells that result from its growth and segmentation cohere until a multicellular aggregate results, the different regions of which fall into certain statical states in relation to one another and to the earth's centre, in virtue of the action of the forces of cohesion, friction, gravitation, etc. The different regions of such an aggregate now adjust themselves to the surroundings in such a way that nearly constant effects of light, heat, etc., begin to control or affect the functions of such an aggregate dynamically through its metabolism. Function, thus conditioned, asserts itself under the stress of mechanical adaptation or adjustment that becomes increasingly complex with every advance in ontogeny. Every step in ontogeny becomes mechanically adaptive and determinative of the next. It is thus only that we can understand the wonderful molecular sorting process that goes on in ontogeny, for which others have invoked infinite multitudes of needless 'gemmules,' 'biophors' and 'determinants.'

It is the whole organism that develops in continuity or coördination ; not its nuclei, centrosomes, and asters only. The whole organism, molecularly considered, is as fixed and immutable, within variable limits, as a crystal. Its development, moreover, becomes intelligible only if we contemplate its ontogeny somewhat as we would the growth of a crystal, with the additional supposition that its growth is not conditioned by forces operating along straight lines having a constant angular divergence as in the latter. On the contrary, living matter is capable of developing curved bounding surfaces in consequence of the permanently mobile nature and cohesion of its molecules, that, as a complex dynamical mechanism, can operate so as to tell off the tale of its transformation in but one way, in consequence of the order and way in which the energy of its constituent molecules is set free during ontogeny. Upon the completion of ontogeny a phrase is reached in which the income and outgo of metabolism is in equilibrium. The duration of life depends upon the length of time that this equilibrium can be maintained without fatal impairment of the harmonious operation of its mechanism under the stress of the dynamical conditions of life. This may be considered the cause of death, so that the length of the life of the individual is determined by the possible number of harmonious molecular transformations of which its plasma is capable as a mechanism.

The doctrine that cells undergo differentiation in relation to other adjacent cells, or that the destiny of a cell is a function of its position (Driesch), is no doubt true. Nevertheless, we have in organisms machines of such complexity, dynamical potentiality, and power of transformation, that in comparison a study of the theories of crystallography is simplicity itself. In organisms we have the polarities of head and tail, stem and root, right, left, dorsal and ventral aspects, as definitely marked out as are the relations of the axes of crystals. In the organism we have diffuse, intussusceptional growth in three dimensions, by means of the osmotic interpolation of new molecules, whereas, in the crystal, growth is superficial, but consequently also tri-dimensional. In the organism the molecules are mobile within limits ; in the crystal they are fixed. Nevertheless, we may justly regard organisms as developing after the manner of crystals, but with the power of very gradually varying their forms by means of variation in the structure, forms and powers of their constituent molecules, in the course of many generations of individuals.

This variation may be directed by the concurrence of a series of natural conditions operating dynamically (natural selection). Or, interbreeding and crossing, with care or under Nature, may unite by means of reciprocal integration (fertilization) two molecular mechanisms whose total structure and sum when thus united, as in sexual reproduction, may vary by the mere combination of the two dynamical systems (egg and sperm), differing slightly from one another in potentiality. Finally, adaptive changes may be called forth dynamically in the internal structure of such developing reciprocally integrated systems that must be traced back to changes in the mechanism of metabolism of the parent as well as in the germs it gives off. Such changes produced in the germ must become visible in the effects they produce, as transmitted formal changes exhibited in the course of development.

The tendency or trend of development, however, of a given form must be pretty constant, and controlled within comparatively narrow limits by the initial adult or attained structure. That is, what has been attained must formally affect that which is to be attained in future. This is the idea that underlies the *Vervollkommnungs-Princip*, principle of perfecting, of Nägeli. This view also tacitly recognizes the theory of change of function proposed by Dohrn, as well as the theories of substitution, superposition and epimorphosis of Kleinenberg, Spencer and Haacke. Once a condition of stable equilibrium has been reached in the series of transformation of the molecular mechanism represented by the germ, during the development of an organism, we may have what Eimer has called *Genepistasis*, resulting in the fixity or stability of an organic species, under stable conditions.

The cell is a complete organism, but it loses its physiological and morphological autonomy when combined with other cells. We may regard the nucleus, cytoplasm and centrosome as reciprocally related parts; one of them not much more important than the others. The observed behavior of the centrosome would indicate, as Verworn has held, that it is the important agent in cellular metabolism. If this is true, metabolism has certain centers in the cell to and from which molecular transformations are effected rythmically in every direction, with the centrosome as focal points. This view agrees perfectly with the facts, since the rays of the asters may be regarded as the morphological expression of a dynamical process of intermolecular diffusion due to metabolism, as Kölliker has suspected (*Gewebelehre*, 6th ed.).

Such a process would not only serve to alter the surface and interfacial-tensions of the cells during ontogeny, but also vary the osmotic pressure within them. Consequently, we may conceive that all of the phenomena of development, including the appearance and disappearance of cavities within a germ by changing conditions of osmosis, may receive a dynamical explanation. The centrosomes may, moreover, be conceived to lie at the foci of very complex material figures, the boundaries of which are finite equipotential cellular surfaces. These focal points are clearly near or within the nuclei. The equipotential surfaces developed by the sorting or readjusting process that goes on during segmentation in order continually and rythmically to restore the dynamical equilibrium of the molecular germinal aggregate as a mechanically constructed system during life and development, through growth and metabolism, must maintain the shapes of organisms as we see them. The epigenetic theory of inheritance therefore promises us a secure basis upon which to found a theory of the mechanics of development, as well as a theory of the origin of morphological types.

The theory of life may indeed be regarded as having its foundations in cellular, inter- and intra-cellular mechanics and dynamics as conditioned by ontogentic metabolism. The fact that centrosome, nucleus and cytoplasm are represented almost coextensively with the presence of life itself is proof that the fundamental machinery of organization must be the same in the principles of its action, no matter how widely its forms may differ from one another.

The theory that the surface layer of molecules of organisms, whether interior or exterior, are in equilibrium also carries with it the idea that the configuration of all organs and organisms are merely the material expression of gradually built up equipotential surfaces. This gives us a far more rational foundation for a theory of general morphology than the hypothesis of gemmaria proposed by Haacke. During growth and metamorphosis these equipotential surfaces undergo formal changes in size and shape, due to the internal processes of molecular transformation or metabolism. But such changes are continuous, and one stage or form passes into the next palpable one through an infinite number of slightly different forms. Examples of such surfaces may be seen in any organism, vegetable or animal, and at any stage of the same. The principle is therefore of universal application.

SUMMARY.—Preformation of any organism in the germ has no foundation in fact.

All that it is possible to account for upon the basis of a theory of preformation may be much more logically and scientifically accounted for upon the ground of dynamical theory. Such a theory must deny the existence of separate corpuscles or gemmules of any sort in the germ, whose business it is to control development. All that is required is the assumption of a determinate ultra-microscopic molecular mechanism, the initial structure of which determines all of its subsequent transformations. The present theory also denies that there is or can be anything passive in the germ that enters into its composition.

A dynamical hypothesis of inheritance is correlated with all the facts of physiology. It is in harmony with the dynamical theory of sex, that sees only in sexuality the means developed by another dynamical process (natural selection) that increases the powers of a compound germ to survive and vary. It is consistent with the facts of morphological super-position, with the dynamical theory of the limit of growth, and duration of life of organic species. It is also consistent with the view that the initial or potential states of the germs of species are those that must result whenever they are relieved from physiological service to the parent organism. The apparent continuity of germ-plasm is, in many cases, only an effect of the equilibration of the forces of the organism, and has no further significance. It must also deny any assumed isotropy of the germ as inconsistent with fact. It assumes that the æolotropy of the molecular structure of the germ is followed by a gradually increasing simplification of molecular structure of organs as these are built up. Metabolism is assumed to be the sole agent in effecting the mechanical and dynamical rearrangement or sorting of the molecules into organs during development. Specially endowed corpuscles or 'biophors' are not only needless as conditioning form or function, but also out of the question, dynamically considered. No creature can be supposed to have its life or germinal properties associated only with certain corpuscles within it, since we cannot suppose an organized whole dominated by a portion of it; it is not possible, for example, to conceive of individual life except from the entire organism that manifests it. There can be no 'biophors'—bearers of life; the whole organism must do that as an indivisible unit. Corpuscular doctrines of inheritance are merely a survival in philosophical hypothesis of a pre-Aristotelian *deus ex machina.* The dynamical hypothesis rejects the *deus ex machina,* but finds a real mechanism in the germ that is an automaton, but that is such only in virtue of its structure and the potential energy stored up within it. Every step in the transformation of such a mechanism is mechanically conditioned within limits by what has preceded it, and which in turn so conditions within limits what is to follow, and so on forever through a succession of descendants. The theory of equipotential surfaces, as here applied to organisms, leads to a theory of general morphology that holds of all living forms, and that is at the same time consistent with the facts of development.

EXPLANATORY NOTE TO PARAGRAPH ON PAGE 618.

It now appears that the statement that the quarters or eighths of an oösperm are to be regarded as 'molecular mechanisms of precisely the same type of potentiality' as the whole egg, must be taken with considerable qualification. Loeb (Ueber die Grenzen der Theilbarkeit der Eisubstanz, *Archiv für Ges. Physiologie,* vol. LIX., 1894) has shown that the eggs of echinoderms, if artificially divided, by means of a method of his devising, into quarters or eighths, lose the power of developing beyond the blastula stage. This would appear to indicate that if the egg is subdivided so as to have its parts fall below a certain size, these parts no longer have locked up within them, as molecular mechanisms, as Loeb points out, enough potential energy to transform themselves into completely equipped larvæ. Or, perhaps, the initial æolotropy of the egg does not permit of its subdivision into quarters and eighths without impairing their structure and powers of development.

My own recent experiments have shown that it is possible to incubate for some time the germ of the bird's egg outside of the egg-shell in a covered glass-dish. These experiments also show that restraints to growth developed by the dying of a film of albumen over the germ causes it to be most extraordinarily folded, with many abnormal tumor-like growths from both entoderm and ectoderm, that differ, however, in histological character from the cells of both these layers. These experiments also prove that it is possible to mechanically divide the germ of the warm-blooded Avian type into halves or quarters, and to have these continue to develop for a time.

The converse of the process of mechanical division of the germ we have in Born's remarkable experiments in cutting recently-hatched Amphibian embryos in two, and placing the separated halves again in contact under such conditions as to cause them to grow together, or even to thus graft the half of a larva of one species upon that of another. That such grafting is possible, I can testify, as a result of a repetition of some of the experiments. See Born's paper in *Schlessischen Gesellsch. f. väterländische Cultur: Medicinische Section,* 1894. pp. 13. Supplementing Born's results are Roux's experiments on *cytotropism,* or the reciprocal attraction of isolated blastomeres of Amphibian eggs (*Archiv f. Entwickelungsmechanik,* I., 1894), if brought close together, though at first not in actual contact. There is also some evidence of asexual *caryotropism* as witnessed in the conjugating nuclei of the cells of the intestinal epithelium of land-Isopods (Ryder and Pennington, *Anat. Anzeiger,* 1894).

The experiments of O. Schultze (*Anat. Anzeiger,* Ergänzungsheft zum Bd. IX., pp. 117–132, 1894), by very slowly rotating in a mechanically fixed position the segmenting eggs of Amphibians on a specially constructed clinostaf, with the result of disorganizing and killing them, show that such eggs are not isotropic. His production of double monsters in such ova by disturbing, for a time, their geotropic relations, is also significant, while his conversion of the meroblastic amphibian egg into a holoblastic, evenly segmenting one by merely rotating it through 180° out of its normal geotropic relation, and allowing it to complete its segmentation in an inverted position, proves that the egg can be made structurally homogenous by mere mechanical means, but at the expense of its power to complete its development. This is further proof that the egg is not isotropic in the sense in which that word is used by natural philosophers.

Since the appearance of the short but important paper by Prof. E. B. Wilson and A. P. Mathews (*Jour. of Morphology,* Vol. X., No. 1, 1895), in which they deny the existence of the centrosome, it becomes necessary for me to explain that the word 'centrosome' is used in the text in the sense in which they use the expression 'attraction spheres.' Their discovery that the ovocenter, or attraction sphere of the egg, disappears after the expulsion of the two polar cells in echinoderm eggs, to be replaced by the sperm-center, is of the greatest significance, and may explain the reason why parthenogenetic eggs develop, namely, as a consequence of their retention of an ovocenter. The new facts that these two able workers have disclosed are entirely in harmony with a dynamical theory of fertilization and sex.

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