part not only in the operations of synthetic metabolism or chemical synthesis, but also in the *morphological determination of these operations*, *i.e.* the morphological synthesis of Bernard — a point of capital importance for the theory of inheritance, as will appear beyond.

Convincing experiments of the same character and leading to the same result have been made on the cells of plants. Francis Darwin ('77) observed more than twenty years ago that movements actively continued in protoplasmic filaments, extruded from the leaf-hairs of *Dipsacus*, that were completely severed from the body of the cell. Conversely, Klebs ('79) soon afterward showed that naked protoplasmic fragments of *Vaucheria* and other algæ were incapable of forming a new cellulose membrane if devoid of a nucleus; and he afterward showed ('87) that the same is true of *Zygnema* and *Œdogonium*. By plasmolysis the cells of these forms may be broken up into fragments, both nucleated and non-nucleated. The former surround themselves with a new wall, grow, and develop into complete plants; the latter, while able to form starch by means of the chlorophyll they contain, are incapable of utilizing it, and are devoid of the power of forming a new membrane, and of growth and regeneration. A beautiful confirmation of this is given by Townsend ('97), who finds in the case of root-hairs and pollen-tubes, that when the protoplasm is thus broken up, a membrane may be formed by both nucleated and non-nucleated fragments, by the latter however *only when they remain connected with the nucleated masses* by protoplasmic strands, however fine. If these strands be broken, the membrane-forming power is lost. Of very great interest is the further observation (made on leaf-hairs in *Cucurbita*) that the influence of the nucleus may thus extend from cell to cell, an enucleated fragment of one cell having the power to form a membrane if connected by intercellular bridges with a nucleated fragment of an adjoining cell (Fig. 161).

2. *Position and Movements of the Nucleus*

Many observers have approached the same problem from a different direction by considering the position, movements, and changes of form in the nucleus with regard to the formative activities in the cytoplasm. To review these researches in full would be impossible, and we must be content to consider only the well-known researches of Haberlandt ('77) and Korschelt ('89), both of whom have given extensive reviews of the entire subject in this regard. Haberlandt's studies related to the position of the nucleus in plant-cells with especial regard to the growth of the cellulose membrane. He determined the very significant fact that local growth of the cell-wall is always preceded by a movement of the nucleus to the point of growth. Thus, in the formation of epidermal cells, the nucleus lies at first near the centre, but as the outer wall thickens, the nucleus moves toward it, and remains closely applied to it throughout its growth, after which the nucleus often moves into another part of the cell (Fig. 162, *A*, *B*). That this is not due simply to a movement of the nucleus toward the air and light is beautifully shown in the coats of certain seeds, where the nucleus moves, not to the outer, but to the inner wall of the cell, and here the thickening takes place (Fig. 162, *C*). The same position

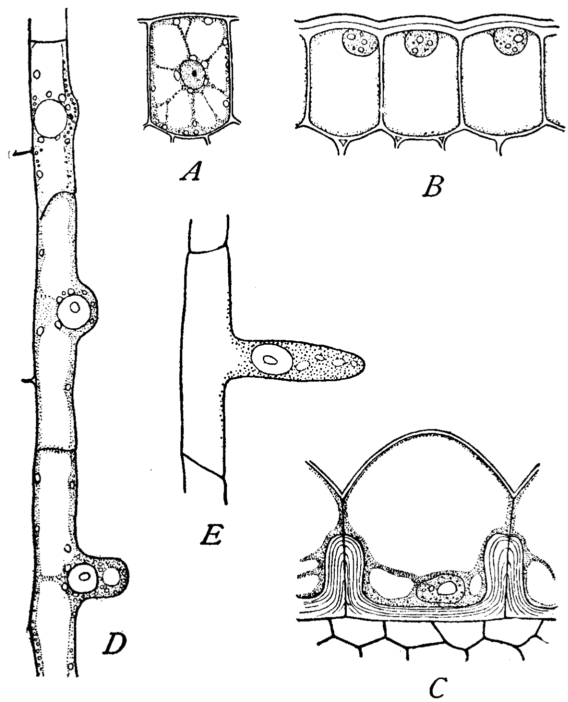

Fig. 162. — Position of the nuclei in growing plant-cells. [HABERLANDT.]

A. Young epidermal cell of *Luzula* with central nucleus, before thickening of the membrane. *B*. Three epidermal cells of *Monstera*, during the thickening of the outer wall. *C*. Cell from the seed-coat of *Scopulina*, during the thickening of the inner wall. *D*. *E*. Position of the nuclei during the formation of branches in the root-hairs of the pea.

of the nucleus is shown in the thickening of the walls of the guard-cells of stomata, in the formation of the peristome of mosses, and in many other cases. In the formation of root-hairs in the pea, the primary outgrowth always takes place from the immediate neighbourhood of the nucleus, which is carried outward and remains near the tip of the growing hair (Fig. 162, *D*, *E*). The same is true of the rhizoids of fern-prothallia and liverworts. In the hairs of aërial plants this rule is reversed, the nucleus lying near the base of the hair; but this apparent exception proves the rule, for both Hunter and Haberlandt show that in this case growth of the hair is not apical, but proceeds from the base! Very interesting is Haberlandt's observation that in the regeneration of fragments of *Vaucheria* the growing region, where a new membrane is formed, contains no chlorophyll, but numerous nuclei. The general result, based on the study of a large number of cases, is, in Haberlandt's words, that "the nucleus is in most cases placed in the neighbourhood, more or less immediate, of the points at which growth is most active and continues longest." This fact points to the conclusion that "its function is especially connected with the developmental processes of the cell,"[1] and that "in the growth of the cell, more especially in the growth of the cell-wall, the nucleus plays a definite part."

Korschelt's work deals especially with the correlation between form and position of the nucleus and the nutrition of the cell, and since it bears more directly on chemical than on morphological synthesis, may be only briefly reviewed at this point. His general conclusion is that there is a definite correlation, on the one hand, between the position of the nucleus and the source of food-supply, on the other hand, between the size of the nucleus and the extent of its surface and the elaboration of material by the cell. In support of the latter conclusion many cases are brought forward of secreting cells in which the nucleus is of enormous size and has a complex branching form. Such nuclei occur, for example, in the silk-glands of various lepidopterous larvæ (Meckel, Zaddach, etc.), which are characterized by an intense secretory activity concentrated into a very short period. Here the nucleus forms a labyrinthine network (Fig. 14, *E*), by which its surface is brought to a maximum, pointing to an active exchange of material between nucleus and cytoplasm. The same type of nucleus occurs in the Malpighian tubules of insects (Leydig, R. Hertwig), in the spinning-glands of amphipods (Mayer), and especially in the nutritive cells of the insect ovary already referred to at page 151. Here the developing ovum is accompanied and surrounded by cells, which there is good reason to believe are concerned with the elaboration of food for the egg-cell. In the earwig *Forficula* each egg is accompanied by a single large nutritive cell (Fig. 163), which has a very large nucleus rich in chromatin (Korschelt). This cell increases in size as the ovum grows, and its nucleus assumes the complex branching form shown in the figure. In the butterfly *Vanessa* there is a group of such cells at one pole of the egg, from which the latter is believed to draw its nutriment (Fig. 77). A very interesting case is that of the annelid *Ophryotrocha*, referred to at page 151. Here, as described by Korschelt, the egg floats

[1] *l.c.*, p. 99.

in the perivisceral fluid, accompanied by a nurse-cell having a very large chromatic nucleus, while that of the egg is smaller and poorer in chromatin. As the egg completes its growth, the nurse-cell dwindles away and finally perishes (Fig. 76). In all these cases it is scarcely possible to doubt that the egg is in a measure relieved of the task of elaborating cytoplasmic products by the nurse-cell, and that the great development of the nucleus in the latter is correlated with this function.

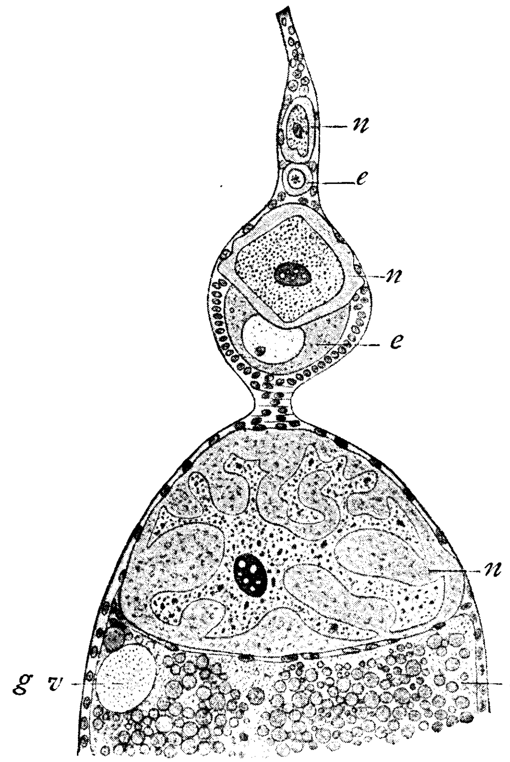

Fig. 163. — Upper portion of the ovary in the earwig *Forficula*, showing eggs and nurse-cells. [KORSCHELT.]

Below, a portion of the nearly ripe egg (*e*), showing deutoplasm-spheres and germinal vesicle (*g.v.*). Above it lies the nurse-cell (*n*) with its enormous branching nucleus. Two successively younger stages of egg and nurse are shown above.

Regarding the position and movements of the nucleus, Korschelt reviews many facts pointing toward the same conclusion. Perhaps the most suggestive of these relate to the nucleus of the egg during its ovarian history. In many of the insects, as in both the cases referred to above, the egg-nucleus at first occupies a central position, but as the egg begins to grow, it moves to the periphery on the side turned toward the nutritive cells. The same is true in the ovarian eggs of some other animals, good examples of which are afforded by various cœlenterates, *e.g.* in medusæ (Claus, Hertwig) and actinians (Korschelt, Hertwig), where the germinal vesicle is always near the point of attachment of the egg. Most suggestive of all is the case of the water-beetle *Dytiscus*, in which Korschelt was able to observe the movements and changes of form in the living object. The eggs here lie in a single series alternating with chambers of nutritive cells. The latter contain granules which are believed by Korschelt to pass into the egg, perhaps bodily, perhaps by dissolving and entering in a liquid form. At all events, the egg contains accumulations of similar granules, which extend inward in dense masses from the nutritive cells to the germinal vesicle, which they may more or less completely surround. The latter meanwhile becomes amœboid, sending out long pseudopodia, which are always directed toward the principal mass of granules (Fig. 77). The granules could not be traced into the nucleus, but the latter grows rapidly during these changes, proving that matter must be absorbed by it, probably in a liquid form.[1]

Among other facts pointing in the same direction may be mentioned Miss Huie's ('97) observations on the gland-cells of *Drosera*, and those of Mathews ('99) on the changes of the pancreas-cell in *Necturus*. Stimulus of the gland-cells in the leaf of *Drosera* causes a rapid exhaustion and change of staining-capacity in the cytoplasm. During the ensuing repose the cytoplasm is rebuilt out of material laid down immediately around the nucleus, and agreeing closely in appearance and staining-reaction with the achromatic nuclear constituents. The chromatin increases in bulk during a period preceding the constructive phase, but decreases (while the nucleolar material increases) as the cytoplasm is restored. In the pancreas-cell, as has long been known, the "loaded" cell (before secretion) is filled with metaplasmic zymogen-granules, which disappear during secretion, the cell meanwhile becoming filled with protoplasmic fibrils (Fig. 18). During the ensuing period of "rest" the zymogen-granules are re-formed at the expense of the fibrillar material, which is finally found only at the base of the cell near the nucleus. Upon discharge of the secretion (granule-material) the fibrillæ again advance from the nucleus toward the periphery. Mathews shows that many if not all of them may be traced at one end actually into the nuclear wall, and concludes that they are directly formed by the nucleus.

Beside the foregoing facts may be placed the strong evidence reviewed at pages 156–158, indicating the formation of the yolk-nucleus, and indirectly of the yolk-material, by the nucleus. All of these and a large number of other observations in the same direction lead to the conclusion that the cell-nucleus plays an active part in nutrition, and that it is especially active during the constructive phases. On the whole, therefore, the behaviour of the nucleus in this regard is in harmony with the result reached by experiment on the one-celled forms, though it gives in itself a far less certain and convincing result.[2]

[1] Mention may conveniently here be made of Richard Hertwig's interesting observation that in starved individuals of *Actinosphærium* the chromatin condenses into a single mass, while in richly fed animals it is divided into fine granules scattered through the nucleus ('98, p. 8).

[2] Loeb ('98, '99) makes the interesting suggestion that the nucleus is especially concerned in the oxydative processes of the cell, and that this is the key to its *rôle* in the synthetic process. It has been shown that oxydations in the living tissues are probably

We now turn to evidence which, though less direct than the above, is scarcely less convincing. This evidence, which has been exhaustively discussed by Hertwig, Weismann, and Strasburger, is drawn from the history of the nucleus in mitosis, fertilization, and maturation. It calls for only a brief review here, since the facts have been fully described in earlier chapters.

3. *The Nucleus in Mitosis*

To Wilhelm Roux ('83) we owe the first clear recognition of the fact that the transformation of the chromatic substance during mitotic division is manifestly designed to effect a precise division of all its parts, — *i.e.* a panmeristic division as opposed to a mere mass-division, — and their definite distribution to the daughter-cells. "The essential operation of nuclear division is the division of the mother-granules" (*i.e.* the individual chromatin-grains); "all the other phenomena are for the purpose of transporting the daughter-granules derived from the division of a mother-granule, one to the centre of one of the daughter-cells, the other to the centre of the other." In this respect the nucleus stands in marked contrast to the cytoplasm, which undergoes on the whole a mass-division, although certain of its elements, such as the plastids and the centrosome, may separately divide, like the elements of the nucleus. From this fact Roux argued, first, that different regions of the nuclear substance must represent different qualities, and second, that the apparatus of mitosis is designed to distribute these qualities, according to a definite law, to the daughter-cells. The particular form in which Roux and Weismann developed this conception has now been generally rejected, and in any form it has some serious difficulties in its way. We cannot assume a precise localization of chromatin-elements in all parts of the nucleus; for on the one hand a large part of the chromatin may degenerate or be cast out (as in the maturation of the egg), and on the other hand in the Protozoa a small fragment of the nucleus is able to regenerate the whole. Nevertheless, the essential fact remains, as Hertwig, Kölliker, Strasburger, De Vries, and many others have insisted, that in mitotic cell-division the chromatin of the mother-cell is distributed with the most scrupulous equality to the nuclei of the daughter-cells, and that in this regard there is a most remarkable contrast between nucleus and cytoplasm. This holds true with such wonderful constancy

dependent upon certain substances (oxydation ferments) that in some manner, not yet clearly understood, facilitate the process; and the work of Spitzer ('97) has shown that these substances (obtained from tissue-extracts) belong to the group of nucleo-proteids, which are characteristic nuclear substances. The view thus suggested opens a further way toward more exact inquiry into the nuclear functions, though it is not to be supposed that the nucleus is the sole oxydative centre of the cell, as is obvious from the prolonged activity of non-nucleated protoplasmic masses.

throughout the series of living forms, from the lowest to the highest, that it must have a deep significance. And while we are not yet in a position to grasp its full meaning, this contrast points unmistakably to the conclusion that the most essential material handed on by the mother-cell to its progeny is the chromatin, and that this substance therefore has a special significance in inheritance.

4. *The Nucleus in Fertilization*

The foregoing argument receives an overwhelming reënforcement from the facts of fertilization. Although the ovum supplies nearly all the cytoplasm for the embryonic body, and the spermatozoön at most only a trace, the latter is nevertheless as potent in its effect on the offspring as the former. On the other hand, the nuclei contributed by the germ-cells, though apparently different, become in the end exactly equivalent in every visible respect — in structure, in staining-reactions, and in the number and form of the chromosomes to which each gives rise. But furthermore the substance of the two germ-nuclei is distributed with absolute equality, certainly to the first two cells of the embryo, and probably to all later-formed cells. The latter conclusion, which long remained a mere surmise, has been rendered nearly a certainty by the remarkable observations of Rückert, Zoja, and Häcker, described in Chapters IV. and VI. We must therefore accept the high probability of the conclusion that the specific character of the cell is in the last analysis determined by that of the nucleus, that is by the chromatin, and that in the equal distribution of paternal and maternal chromatin to all the cells of the offspring we find the physiological explanation of the fact that

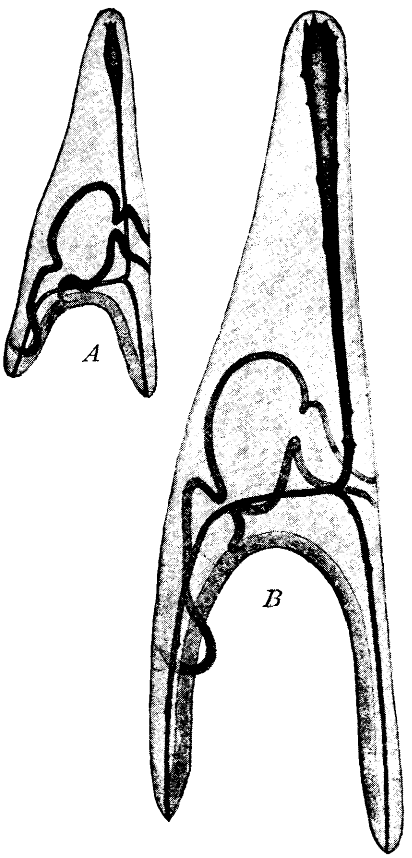

Fig. 164. — Normal and dwarf larvæ of the sea-urchin. [BOVERI.]

A. Dwarf Pluteus arising from an enucleated egg-fragment of *Sphærechinus granularis*, fertilized with spermatozoön of *Echinus microtuberculatus*, and showing *purely paternal characters*. *B.* Normal Pluteus of *Echinus microtuberculatus*.

every part of the latter may show the characteristics of either or both parents.

Boveri ('89, '95, 1) has attempted to test this conclusion by a most ingenious and beautiful experiment; and although his conclusions do not rest on absolutely certain ground, they at least open the way to a decisive test. The Hertwig brothers showed that the eggs of sea-urchins might be broken into pieces by shaking, and that spermatozoa would enter the enucleated fragments and cause them to segment. Boveri proved that such a fragment, if fertilized by a spermatozoön, would even give rise to a dwarf larva, indistinguishable from the normal in general appearance except in size. The nuclei of such larvæ are considerably smaller than those of the normal larvæ, and were shown by Morgan ('95, 4) to contain *only half the number of chromosomes*, thus demonstrating their origin from a single sperm-nucleus. Now, by fertilizing enucleated egg-fragments of one species (*Sphærechinus granularis*) with the spermatozoa of another (*Echinus microtuberculatus*), Boveri obtained in a few instances dwarf Plutei showing except in size *the pure paternal characters* (*i.e.* those of *Echinus*, Fig. 164). From this he concluded that the maternal cytoplasm has no determining effect on the offspring, but supplies only the material in which the sperm-nucleus operates. Inheritance is, therefore, effected by the nucleus alone.

The later studies of Seeliger ('94), Morgan ('95, 4), and Drisch ('98, 3) showed that this result is not entirely conclusive, since hybrid larvæ arising by the fertilization of an entire ovum of one species by a spermatozoön of the other show a very considerable range of variation; and while most such hybrids are intermediate in character between the two species, some individuals may nearly approximate to the characters of the father or the mother. Despite this fact Boveri ('95, 1) has strongly defended his conclusion, though admitting that only further research can definitely decide the question. It is to be hoped that this highly ingenious experiment may be repeated on other forms which may afford a decisive result.

5. *The Nucleus in Maturation*

Scarcely less convincing, finally, is the contrast between nucleus and cytoplasm in the maturation of the germ-cells. It is scarcely an exaggeration to say that the whole process of maturation, in its broadest sense, renders the cytoplasm of the germ-cells as unlike, the nuclei as like, as possible. The latter undergo a series of complicated changes which result in a perfect equivalence between them at the time of their union, and, more remotely, a perfect equality of distribution to the embryonic cells. The cytoplasm, on the other hand, undergoes a special differentiation in each to effect a secondary division of labour between the germ-cells. When this is correlated with the fact that the germ-cells, on the whole, have an equal effect on the specific character of the embryo, we are again forced to the conclusion that this effect must primarily be sought in the nucleus, and that the cytoplasm is in a sense only its agent.

C. The Centrosome

Existing views regarding the functions of the centrosome may conveniently be arranged in two general groups, the first including those which regard this structure as a relatively *passive* body, the second those which assume it to be an active organ. To the first belongs the hypothesis of Heidenhain ('94), accepted by Kostanecki ('97, 1) and some others, that the centrosome serves essentially as an insertion-point for the astral rays ("organic radii"), and plays a relatively passive part in the phenomena of mitosis, the active functions being mainly performed by the surrounding structures. To the same category belongs the view of Miss Foot that the formation of the centrosome is, as it were, incidental to that of the aster — "the expression, rather than the cause, of cell-activity" ('97, p. 810). To the second group belong the views of Van Beneden, Boveri, Bütschli, Carnoy, and others who regard the centrosome as playing a more active *rôle* in the life of the cell. Both of the former authors have assumed the centrosomes to be active centres by the action of which the astral systems are organized; and they are thus led to the conclusion that the centrosome is essentially an organ for cell-division and fertilization (Boveri), and in this sense is the "dynamic centre" of the cell.[1] To Carnoy and Bütschli is due the interesting suggestion[2] that the centrosomes are to be regarded further as centres of *chemical action* to which their remarkable effect on the cytoplasm is due. That the centrosome is an active centre, rather than a passive body or one created by the aster-formation, is strongly indicated by its behaviour both in mitosis and in fertilization. Griffin ('96, '99) points out that at the close of division in *Thalassema* the daughter-centrosomes migrate away from the old astral centre and incite about themselves in a different region the new astral systems for the ensuing mitosis (Figs. 99, 155); and similar conditions are described by Coe in *Cerebratulus* ('98). In fertilization the aster-formation cannot be regarded as a general action of the cytoplasm, but as a local one due to a local stimulus given by something in the spermatozoön; for in polyspermy a sperm-aster is formed for every spermatozoön (p. 198). This stimulus is given by something in the middle-

[1] *Cf.* pp. 76, 192. [2] *Cf.* p. 110.

piece (p. 212), which is itself genetically related to the centrosome of the last cell-generation (p. 170). These facts seem explicable only under the assumption that in these cases the centrosome, or a substance which it carries, gives an active stimulus to the cytoplasm which incites the aster-formation about itself, and in the words of Griffin "disengages the forces at work in mitosis" ('96, p. 174). For these reasons I incline to the view that in the artificial aster-formation described by Morgan[1] the centrosomes there observed should not be regarded as the creations of the asters, but rather as local deposits of material which incite the aster-formation around them. That the centrosomes or astral centres are centres of division (whether active or passive) is beautifully shown by Boveri's interesting observations on "partial fertilization" referred to at page 194.

Again, Boveri has observed that the segmenting ovum of *Ascaris* sometimes contains a supernumerary centrosome that does not enter

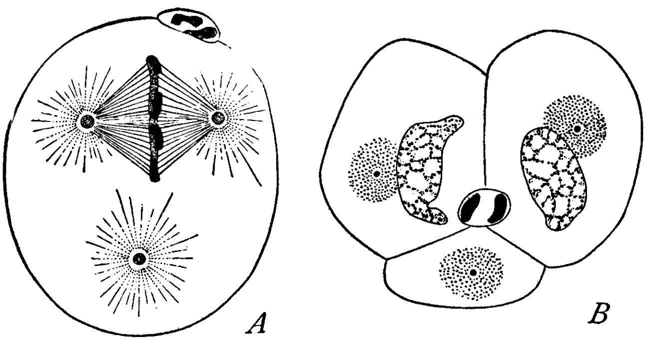

Fig. 165. — Eggs of *Ascaris* with supernumerary centrosome. [BOVERI.]
A. First cleavage-spindle above, isolated centrosome below. *B.* Result of the ensuing division.

into connection with the chromosomes, but lies alone in the cytoplasm (Fig. 165). Such a centrosome forms an independent centre of division, the cell dividing into three parts, two of which are normal blastomeres, while the third contains only the centrosome and attraction-sphere. The fate of such eggs was not determined, but they form a complete demonstration that it is in this case the centrosome and not the nucleus that determines the centres of division in the cell-body. Scarcely less conclusive is the case of dispermic eggs in sea-urchins. In such eggs both sperm-nuclei conjugate with the egg-nucleus, and both sperm-centrosomes divide (Fig. 166). The cleavage-nucleus, therefore, arises by the union of *three* nuclei and *four* centrosomes. Such eggs divide at the first cleavage into four equal blastomeres, each of which receives one of the centrosomes.

[1] *Cf.* p. 307.

The latter must, therefore, be the centres of division;[1] though it must not be forgotten that, in some cases at any rate, normal division requires the presence of nuclear matter (p. 108).

The centrosome must, however, be something more than a mere division-centre; for, on the one hand, in leucocytes and pigment-cells the astral system formed about it is devoted, as there is good reason to believe, not to cell-division, but to movements of the cell-body as a whole; and, on the other hand, as we have seen (pp. 165, 172), it is concerned in the formation of the flagella of the spermatozoa and spermatozoids, and probably also in that of cilia in epithelial cells. Strasburger ('97) was thus led to the conclusion that the centrosome is essentially a mass of *kinoplasm, i.e.* the active motor plasm,[2] and a nearly similar view has been adopted by several recent zoölogists.

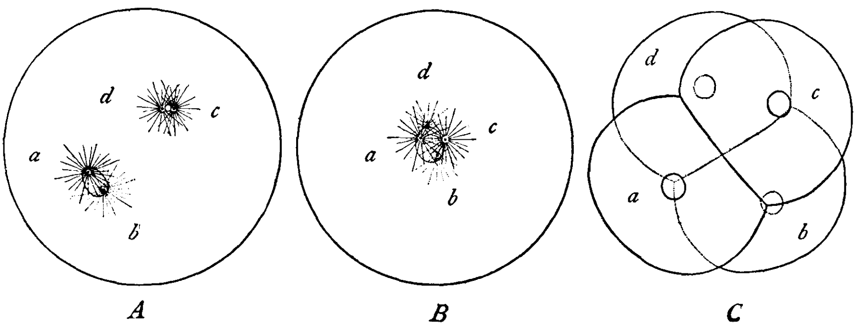

Fig. 166. — Cleavage of dispermic egg of *Toxopneustes*.

A. One sperm-nucleus has united with the egg-nucleus, shown at *a. b.*; the other lies above. Both sperm-asters have divided to form amphiasters (*a. b.* and *c. d.*). *B.* The cleavage-nucleus, formed by union of the three germ-nuclei, is surrounded by the four asters. *C.* Result of the first cleavage, the four blastomeres lettered to correspond with the four asters.

Henneguy concludes that the centrosomes are "motor centres of the kinoplasm" both for external and for internal manifestations.[3] Lenhossék regards them as "motors" for the control of ciliary action as well as for that of the spermatozoön,[4] and perhaps also for that of muscle-fibrillæ.[5] Zimmerman concludes that "the microcentrum is the motor centre of the cell, that is, the 'kinocentrum' opposed to the nucleus as the 'chemocentrum.'"[6] Regarding their control of ciliary action, he makes the same suggestion as that of Henneguy and Lenhossék cited above. He adds the further very interesting suggestions that the centrosomes may be concerned with the pseudopodial movements in the epithelial cells of the intestine, and that they may

[1] This phenomenon was first observed by Hertwig, and afterward by Driesch. I have repeatedly observed the internal changes in the living eggs of *Toxopneustes*.

[2] *Cf.* p. 221.

[3] '98, p. 495.

[4] '98, p. 107.

[5] '99, p. 342.

[6] '98, p. 697.

also be concerned in the protoplasmic contraction of gland-cells by which the excretion is expelled. [This is based on the fact that the centrosomes are found in the free (pseudopodia-forming) ends of the epithelial cells, and on the position of the centrosomes in goblet-cells (Fig. 23) and in those of the lachrymal gland.] Peter ('99) has attempted to test these conclusions experimentally by cutting or tearing off cilia from the cell-body (gut-epithelium of *Anodonta*) and also by isolating the tails of spermatozoa. In groups consisting of only a few cilia, separated from the nucleus, the movements actively continue, while those that are separated from the basal bodies cease to beat. Spermatozoön tails separated from the head also continue to

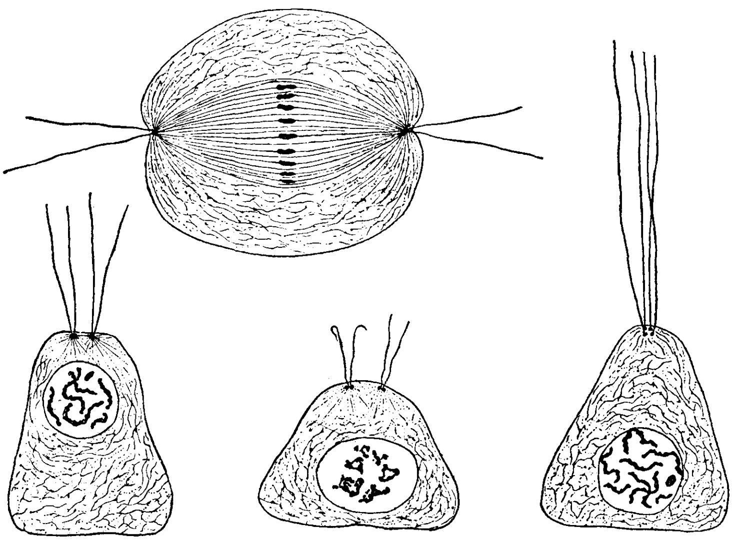

Fig. 167. — Centrosomes and cilia in spermatocytes of a butterfly. [HENNEGUY.]

move, but only if they remain connected with the middle-piece. Peter, therefore, supports the above conclusions of Henneguy and Lenhossék. On the other hand, Meves ('99) finds that movements of the undulating membrane in the tails of salamander-spermatozoa continue if the middle-piece be entirely removed; while a number of earlier observers[1] have observed in flagellates that a flagellum separated from the body may actively continue its movements for a considerable time.

Further research is therefore required to test these suggestions. The intimate connection of the centrosomes with the formation, on the one hand, of the astral rays, on the other of contractile organs, such

[1] See Klebs, '83, Bütschli, '85, Fischer, '94, 2.

as cilia, flagella, and pseudopodia,[1] the centrosomes in ciliated cells and spermatozoa, and in the swarm-spores of *Noctiluca*, is, however, a most striking fact, and is one of the strongest indirect arguments in favour of the general theory of fibrillar contractility in mitosis.

D. Summary and Conclusion

The facts reviewed in the foregoing pages converge to the conclusion that the differentiation of the cell-substance into nucleus and cytoplasm is the expression of a fundamental physiological division of labour in the cell. Experiments upon unicellular forms demonstrate that, in the entire absence of a nucleus, protoplasm is able for a considerable time to liberate energy and to manifest coördinated activities dependent on destructive metabolism. There is here substantial ground for the view that the cytoplasm is the principal seat of these activities in the normal cell. On the other hand, there is strong cumulative evidence that the nucleus is intimately concerned in the constructive or synthetic processes, whether chemical or morphological.

That the nucleus has such a significance in synthetic metabolism is proved by the fact that digestion and absorption of food and growth soon cease with its removal from the cytoplasm, while destructive metabolism may long continue as manifested by the phenomena of irritability and contractility. It is indicated by the position and movements of the nucleus in relation to the food-supply and to the formation of specific cytoplasmic products. It harmonizes with the fact, now universally admitted, that active exchanges of material go on between nucleus and cytoplasm. The periodic changes of staining-capacity undergone by the chromatin during the cycle of cell-life, taken in connection with the researches of physiological chemists on the chemical composition and staining-reactions of the nuclein series, indicate that the phosphorus-rich substance known as *nucleinic acid* plays a leading part in the constructive process. During the vegetative phases of the cell this substance is combined with a large amount of the albumin radicles histon, protamin, and related substances, and probably in part with albumin itself, to form nuclein. During the mitotic or reproductive processes this combination appears to be dissolved, the albuminous elements being in large part split off, leaving the substance of the chromosomes with a high percentage of nucleinic acid, as is shown by direct analysis of the sperm-nucleus and is indicated by the staining-reactions of the chromosomes. There is, therefore, considerable ground for the hypothesis that in a chemical sense this substance is the most essential nuclear element handed

[1] *Cf.* pp. 92, 102, on the central granule of the *Heliozoa*.

on from cell to cell, whether by cell-division or by fertilization; and that it may be a primary factor in the constructive processes of the nucleus and through these be indirectly concerned with those of the cytoplasm.

The *rôle* of the nucleus in constructive metabolism is intimately related with its *rôle* in morphological synthesis, and thus in inheritance; for the recurrence of similar morphological characters must in the last analysis be due to the recurrence of corresponding forms of metabolic action of which they are the outward expression. That the nucleus is in fact a primary factor in morphological as well as chemical synthesis is demonstrated by experiments on unicellular plants and animals, which prove that the power of regenerating lost parts disappears with its removal, though the enucleated fragment may continue to live and move for a considerable period. That the nuclear substance, and especially the chromatin, is a leading factor in inheritance is powerfully supported by the facts of maturation, fertilization, and cell-division. In maturation the germ-nuclei are by an elaborate process prepared for the subsequent union of equivalent chromatic elements from the two sexes. By fertilization these elements are brought together, and by mitotic division distributed with exact equality to the embryonic cells. The result, which is especially striking in the case of hybrid-fertilization, proves that the spermatozoön is as potent in inheritance as the ovum, though the latter contributes an amount of cytoplasm which is but an infinitesimal fraction of that supplied by the ovum.

It remains to be seen whether the chromatin can actually be regarded as the idioplasm or physical basis of inheritance, as maintained by Hertwig and Strasburger. Verworn has justly urged that the nucleus cannot be regarded as the sole vehicle of inheritance, since the coöperation of both nucleus and cytoplasm is essential to complete cell-life; and, as will be shown in Chapter IX., the cytoplasmic organization plays an important *rôle* in shaping the course of development. Considered in all their bearings, however, the facts seem to accord best with the hypothesis that the cytoplasmic organization is itself determined, in the last analysis, by the nucleus;[1] and the principle for which Hertwig and Strasburger contended is thus sustained.

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[1] *Cf.* p. 431.

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