CHAPTER IX

SOME PROBLEMS OF CELL-ORGANIZATION

"We must therefore ascribe to living cells, beyond the molecular structure of the organic compounds that they contain, still another structure of different type of complication; and it is this which we call by the name of organization." BRÜCKE.[1]

Whether structure or function is the primary determining factor in vital phenomena is a question that has been a subject of debate for many generations of biological philosophers. As thus stated, however, the question has proved barren, for all students of the problem have in the end had to admit that structure and function are inseparable. It is certain that vital action is not known to us apart from an organized material basis, and equally certain that vital structures exist only as products of protoplasmic activity. Thus has arisen a dilemma which belongs to the fundamental philosophy of biology and may here be left aside as practically insoluble. The fact of importance to the cytologist is that we cannot hope to comprehend the activities of the living cell by analysis merely of its chemical composition, or even of its molecular structure alone. Many investigators, it is true, including Pflüger, Verworn, Adami and other physiologists have tried to formulate vital activities in terms of the properties of large molecules or *biogens* of which the "living substance" is assumed to be built; and this conception has rendered important service in physiological analysis. Modern investigation has, however, brought ever-increasing recognition of the fact that the cell is an *organic system*, and one in which we must recognize the existence of some kind of ordered structure or *organization*.

The necessity for such a postulate has been as clearly recognized by physiologists and biochemists as by morphologists and cytologists. The eminent investigator, Ernst Brücke was one of the first of a long line of physiologists to insist upon this necessity; and it has not been set aside by conceptions of the cell as a colloidal system, or by modern investigations in biochemistry. "One cannot help assuming," says Jost, "that the mode of arrangement of the ultimate parts of the organism is of greater importance than the chemical nature of these parts" ('07). "It is clear," says F. G. Hopkins, '13, "that the living cell as we now know it, is not a mass of matter composed of live molecules, but a highly differentiated system." Mathews emphasizes the enormous contrast between living protoplasm and the same

[1] Elementarorganismen, p. 386, 1861.

protoplasm after it has been ground up in a mortar without altering its merely chemical or molecular properties. "The orderliness of the chemical reactions (in the cell) is due to the cell-structure, and for the phenomena of life to persist in their entirety that structure must be preserved." [1] The whole mechanistic interpretation of vital processes rests, indeed, upon the assumption that their specific character, and particularly their orderly localization in the system, must somehow depend on what we call their "organization" in Brücke's sense; and even the vitalistic theories cannot free themselves from the same conception. "No one, not even the vitalist, doubts that the organism is a Gibbs system." [2] We cannot, it is true, say precisely what organization is, but we can hardly think of it as other than some kind of material configuration of the protoplasmic substance, and one that involves both a differentiation of parts and their integration to form a whole, as Herbert Spencer long since urged.[3] When, therefore, Loeb (to cite still another physiologist) characterizes the living organism as a chemical or colloidal *machine* ('06) he employs a word that implies the existence of such a configuration; Loeb specifically maintains, indeed, that "without a structure in the egg to begin with, no formation of a complicated organism is conceivable." [4] The same implication lurks behind every attempt to formulate the unity and order of the individual in purely physiological terms, *e. g.*, by ascribing it to "definite relations in both space and time among the reactions occurring in protoplasm." [5] That such a configuration exists is made evident first of all by the fact that "living matter" is known to us only in the form of cells or their products. To a limited extent we are able to see special configurations or structures within the cell correlated with specific modes of action, but such structures are for the most part of secondary origin; they are products of differentiation during embryological development. Since, however, they are hereditary, such specific cell-structures must somehow be predetermined in the germ-cells. Of what nature is this predetermination? Is there in the cell a *primary* or fundamental organization that is handed on from one cell-generation to another without essential change to form the source of the *secondary* or derived organization that may appear anew in each cell-generation? This question, evidently, belongs as much to embryology as to cytology and as such will further be discussed in the closing chapters of this work. Here we are more directly concerned with certain cytological aspects of the problem, which come to a focus in the phenomena of growth, division,

[1] Mathews ('15), p. 11.
[2] Henderson ('17), p. 131.
[3] *Cf.* Conklin, '24.
[4] Loeb, ('16), p. 39.
[5] Child ('15), p. 17.

and differentiation, as displayed by the various formed components of the cell.

Superficially regarded, many of these components *seem* to arise *de novo*, as in case of the chromosomes and chromomeres, and of various forms of cytoplasmic granules, fibrillæ or other structures. Undoubtedly, however, there are many cases in which this impression is not correct. It has long been known that chromosomes are transmitted from cell to cell by division, and recent studies in this field increase the probability that the same is true of smaller bodies or chromomeres of which the chromosomes are in part at least built up (p. 906). We have long been familiar with the fact that certain of the cytoplasmic components, such as the central bodies or the plastids, may likewise be transmitted from cell to cell by growth and division. Nothing is more noteworthy in recent studies on protoplasmic structure and histogenesis than the increasing tendency of cytologists to extend the same conclusion to other cytoplasmic components, such as chondriosomes, chromidia, and possibly the Golgi-bodies and fibrillar structures. It is certain that in some cases the formed components do not arise *de novo* but are largely built up from preëxisting elements or their products derived from earlier generations of cells; examples of this are conspicuously seen in the important part played in the genesis of the egg and sperm by the central bodies, the chondriosomes, and apparently also by the Golgi-bodies associated with the idiozome and astral apparatus.[1] To what extent may the genetic law of continuity, now so strongly supported in case of the nuclear components, likewise apply to those of the cytosome? To this question we shall return after consideration of certain more specific problems of cell-morphology.

I. THE CENTRAL APPARATUS. THE DIVISION-CENTERS AND THEIR DERIVATIVES

There is now no doubt that in many cases the central bodies of the daughter-cells arise by the division of those of the mother-cell; and we must admit that there is a certain presumption in favor of the conclusion of Van Beneden, Boveri and their followers that the division-center (centriole) may be regarded as a permanent and autonomous cell-organ that arises only by the division of a preëxisting body of the same kind. Doubt has been thrown on this conclusion by apparently strong evidence that in certain cases it may arise *de novo*. In the very fact of such a double mode of origin (if it can be accepted) lies the peculiar interest of the central bodies in their relation to the protoplasmic metastructure. We shall later meet with the same problem in relation to the origin of mitochondria and of plastids; but

[1] (Pp. 357, 385).

in case of the central bodies it is made more accessible by their small number and by the frequent presence of a surrounding aster which, as it were, isolates them for observation.

1. The Central Body and Its Relation to the Astral Formations

Much confusion still exists in the literature concerning the terminology and relationships of the central body. Its discoverer, Van Beneden ('76), first called it the "polar corpuscle," later "central corpuscle" ('87). Boveri

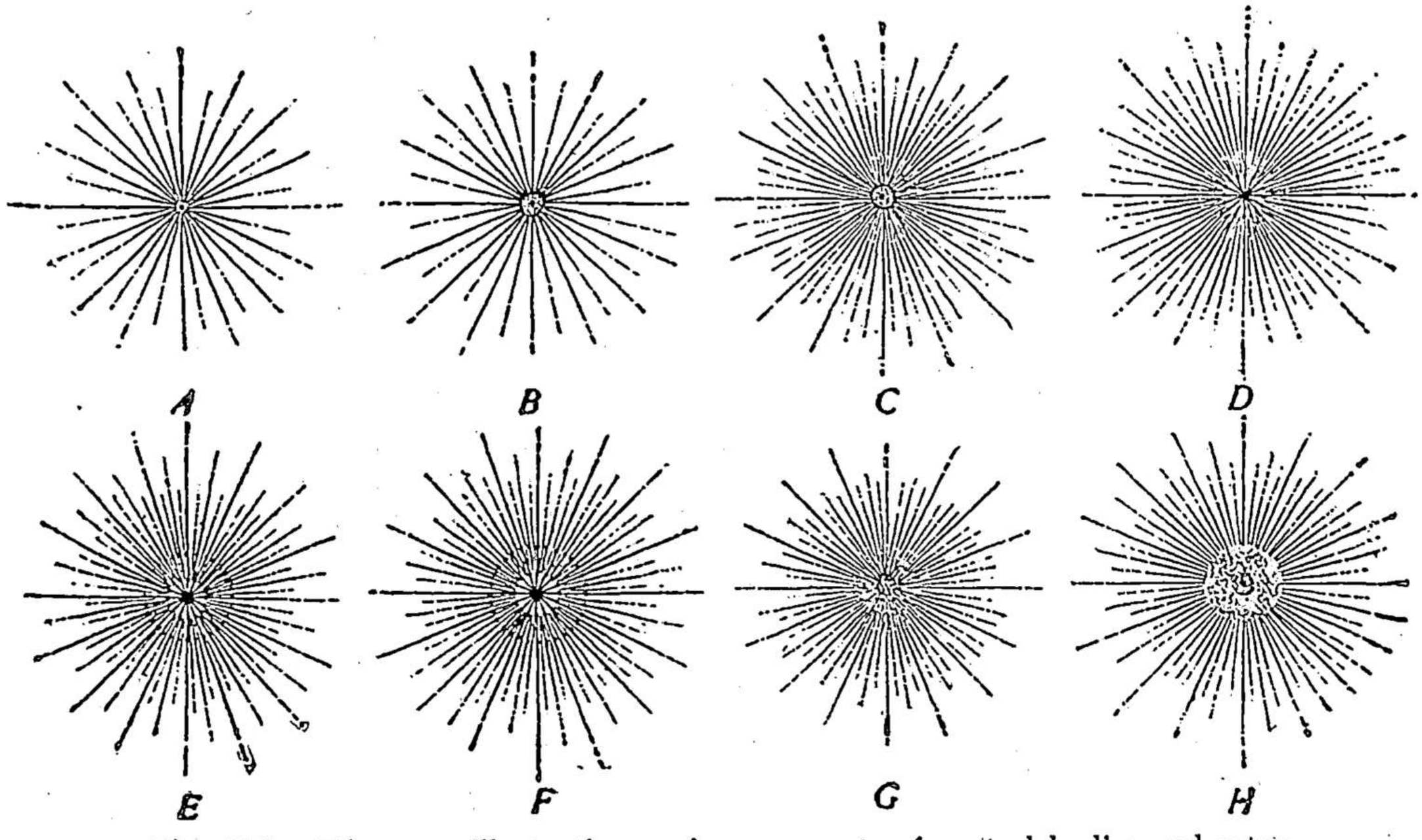

Fig. 321.—Diagrams illustrating various accounts of central bodies and aster.

A, central body a simple granule at the center of the aster; *ex*, sperm-aster in various animals; *B*, "centrosome" a sphere enclosing a central granule or centriole; *ex*, Brauer's account of spermatocytes of *Ascaris; C*, like the last, but "centrosome" surrounded by a clear zone; *ex*, Boveri's account of the centrosome of the *Ascaris* egg; *D*, centriole surrounded by a radial sphere ("centrosome") bounded by a microsome-circle, and lying in a clear zone; *ex*, polar spindles of *Thysanozoön*, Van der Stricht; *E*, centriole surrounded by medullary and cortical radial zones, each bounded by a microsome-circle; *ex*, polar spindle of *Unio*, LILLIE; *F*, Van Beneden's representation of aster of the *Ascaris* egg; like the last, but the "corpuscule central" consisting of a group of granules; *G*, central body a group of granules surrounded by a clear zone; *ex*, the echinoderm-egg; *H*, "centrosome" a large reticulated "centrosphere" containing a new centrosome within which lies the centriole; *ex*, *Rhynchelmis* (VEJDOVSKÝ) or *Arion* (LAMS).

('88) applied to it the term *centrosome*, later describing it as consisting of a specific centroplasm ('01, p. 204), and as forming the central point of attachment for the astral rays. Within it is a much smaller body which Boveri ('95) called the *centriole, which is first of all to divide* and thus to initiate division of the whole astral system and of the cell. This fact, first clearly recognized in *Ascaris*, has received repeated confirmation by later observers.

Boveri at first considered the centrosome as an individualized body that is distinct from the aster, and held that both centriole and centrosome are

persistent structures that grow and divide without loss of their identity; and such may perhaps sometimes be the case. Subsequent studies by many observers, prominent among them Vejdovský and Mrázek ('03), Yatsu ('09) and Lams ('10), demonstrated that in many cases the centrosome is but a transitory structure which, like the surrounding aster, may form, disappear and re-form in successive phases of mitosis. The whole problem thus comes to a focus in the centriole, a consideration of which demands some account of its relations to the centrosome and aster.[1]

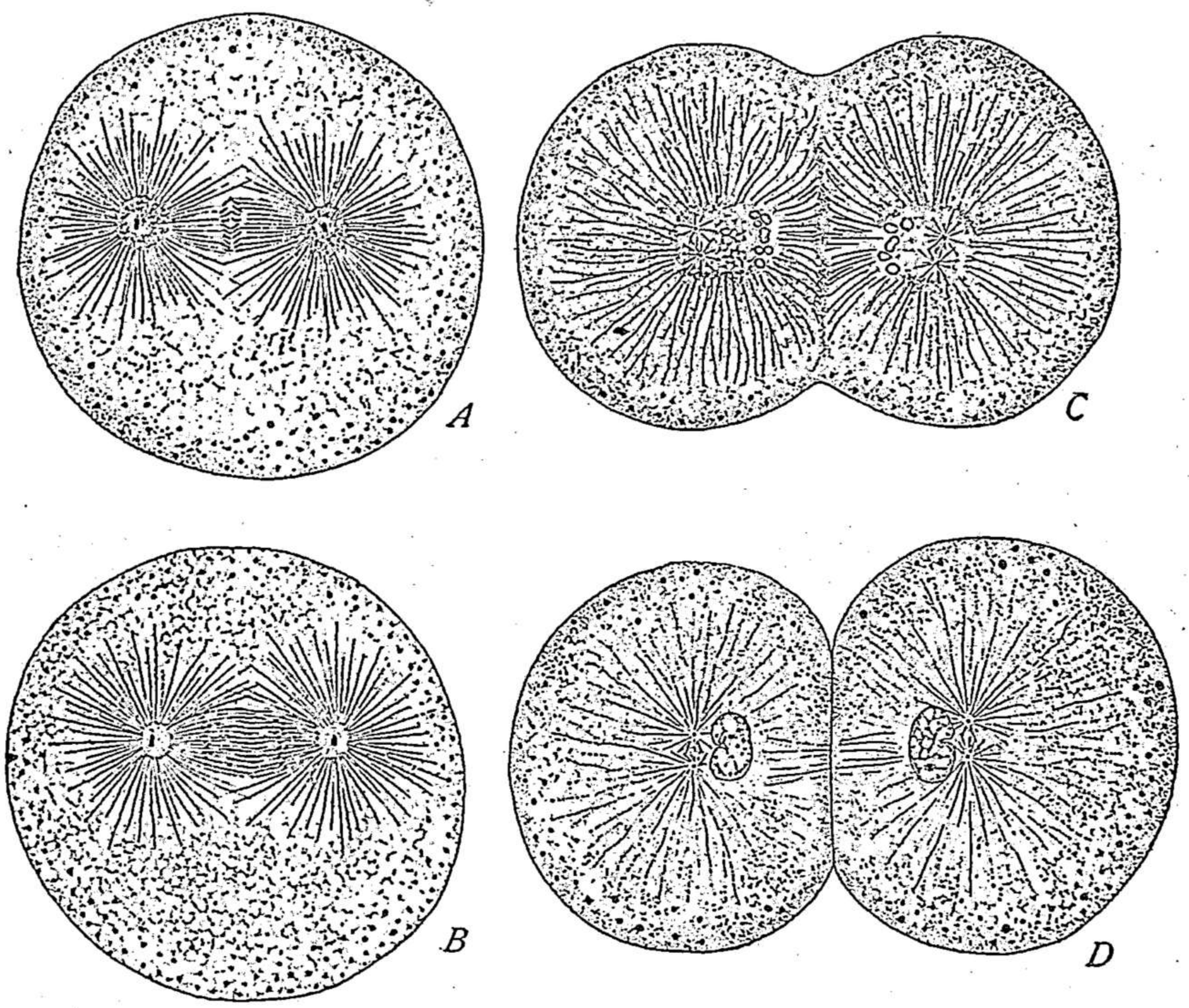

Fig. 322.—First cleavage of the ovum in the nemertine *Cerebratulus* (Coe).

A, initial anaphase, center double; *B*, middle anaphase; *C*, early telophase; daughter-amphiaster; *D*, late telophase.

In its simplest forms (Fig. 321) the central body appears under the highest powers as a single granule of extreme minuteness, staining intensely with iron-hæmatoxylin, crystal violet and some other dyes, and often hardly to be distinguished from a microsome save by the fact that it lies at the

[1] For the literature of the subject see especially the works of Boveri on sea-urchins and *Ascaris* ('95, '01), Van der Stricht on Turbellaria ('98), MacFarland on gasteropods ('97), Lillie on pelecypods ('98), Griffin on annelids ('99), Wilson, general ('00), Meves, critical ('02), Vejdovský and Mrázek ('03), and Vejdovský ('07) on annelids, Heidenhain on leucocytes, etc. ('92, '94, '07), Yatsu on nemertines ('09), and Lams on gasteropods ('10). Also Van Beneden ('93, '87), Boveri ('88) Brauer ('93), Kostanecki ('97), and Kostanecki and Siedlecki ('97) on *Ascaris*, Francotte ('97) and Schockaert ('01) on Turbellaria, Coe on nemertines ('99), Byrnes ('99), Conklin ('03), Smallwood ('04) and Linville ('00), on mollusks.

focus of the astral rays. In this form it appears, for example, in the very young sperm aster during fertilization (Fig. 207) or in its very early prophases during ordinary mitosis, often also in the "resting" or vegetative cells (Figs. 8, 42). In all such cases these bodies are probably to be identified as centrioles, though they are often erroneously called "centrosomes." [1] In the vegetative cells they may be surrounded by a "centrosome," "sphere" or idiozome" (p. 329); but in these cases this surrounding structure usually

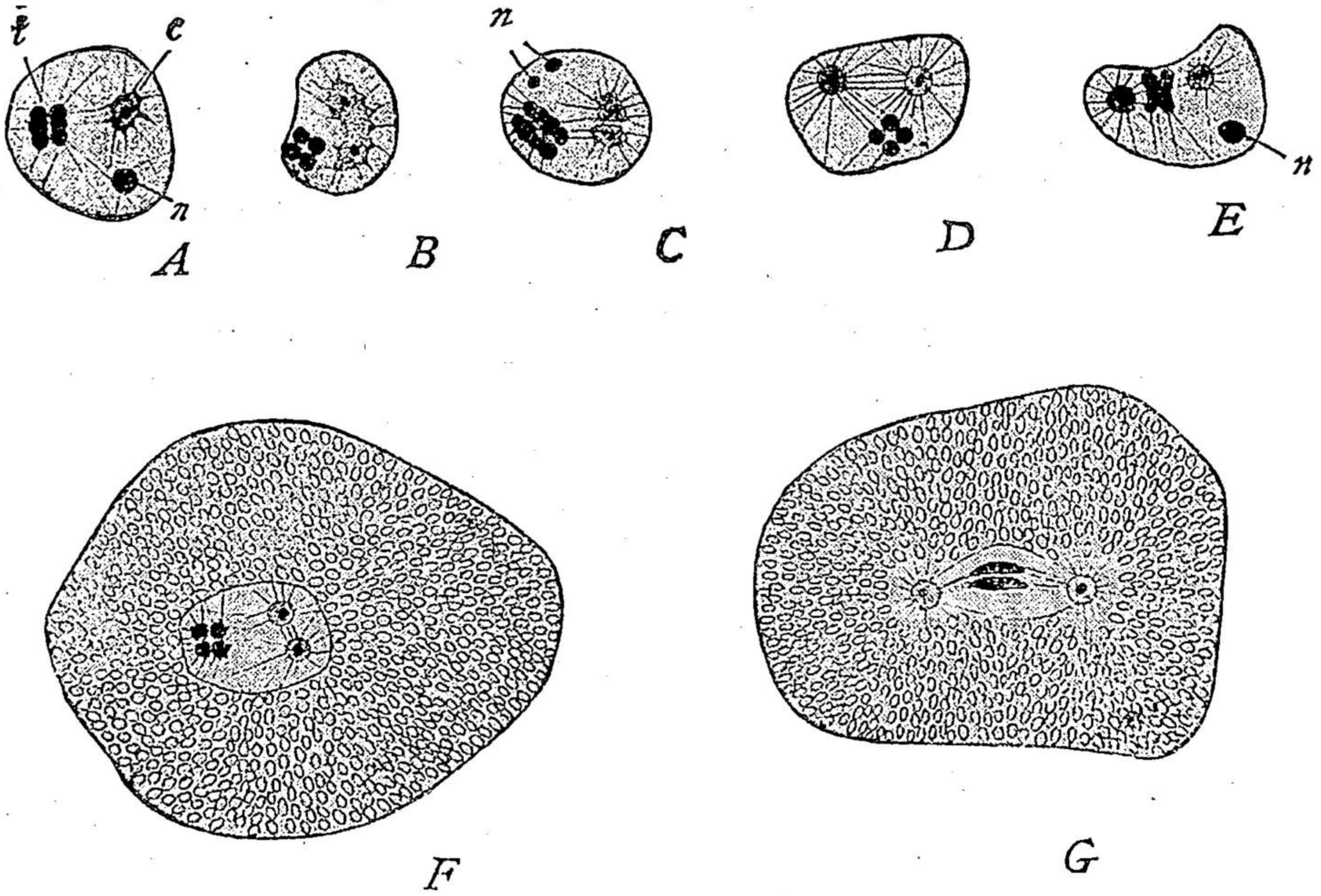

Fig. 323.—Mitosis with intra-nuclear central body in the spermatocytes of *Ascaris megalocephala* var. *univalens* (BRAUER).

A, nucleus containing a quadruple group or tetrad of chromosomes (*t*), nucleolus (*n*), and centrosome containing a centriole (*c*); *B*, *C*, division of the centriole and centrosome; *D*, *E*, *F*, *G*, transformation of the mitotic figure, centrosomes escaping from the nucleus in *G*.

breaks up or degenerates in the early prophases of mitosis, so that the centrioles alone form the focus of the ensuing operations (Figs. 8, 328).

[1] The word "centrosome" will be found in the literature in at least four different senses, namely:

(1) In a general physiological sense as the division-center of the cell.

(2) As the innermost differentiated body at the center of the aster, the only persistent element of the whole system, equivalent to the central granule or centriole (earlier works of Heidenhain, Kostanecki, Coe, Griffin, Wilson, Conklin, etc.).

(3) In Boveri's original sense as a larger body surrounding the centriole, having a persistent identity and independent of the aster.

(4) As a transitory structure, representing the innermost astral zone and thus equivalent to Van Beneden's "medullary zone" (Brauer, Erlanger, Van der Stricht, Lillie, Vejdovský and Mrázek, Lams, and most other recent writers).

It was this ambiguity that led Flemming ('91), and later Heidenhain and many others, to adopt the more inclusive and non-committal terms *central body*, *division-center* or simply *center* in all cases where the genesis of the central apparatus is not fully known.

At a slightly later period during the prophases the centriole (now usually double) is found to be surrounded by a centrosome, which steadily enlarges as mitosis proceeds, while the centrioles remain very minute.

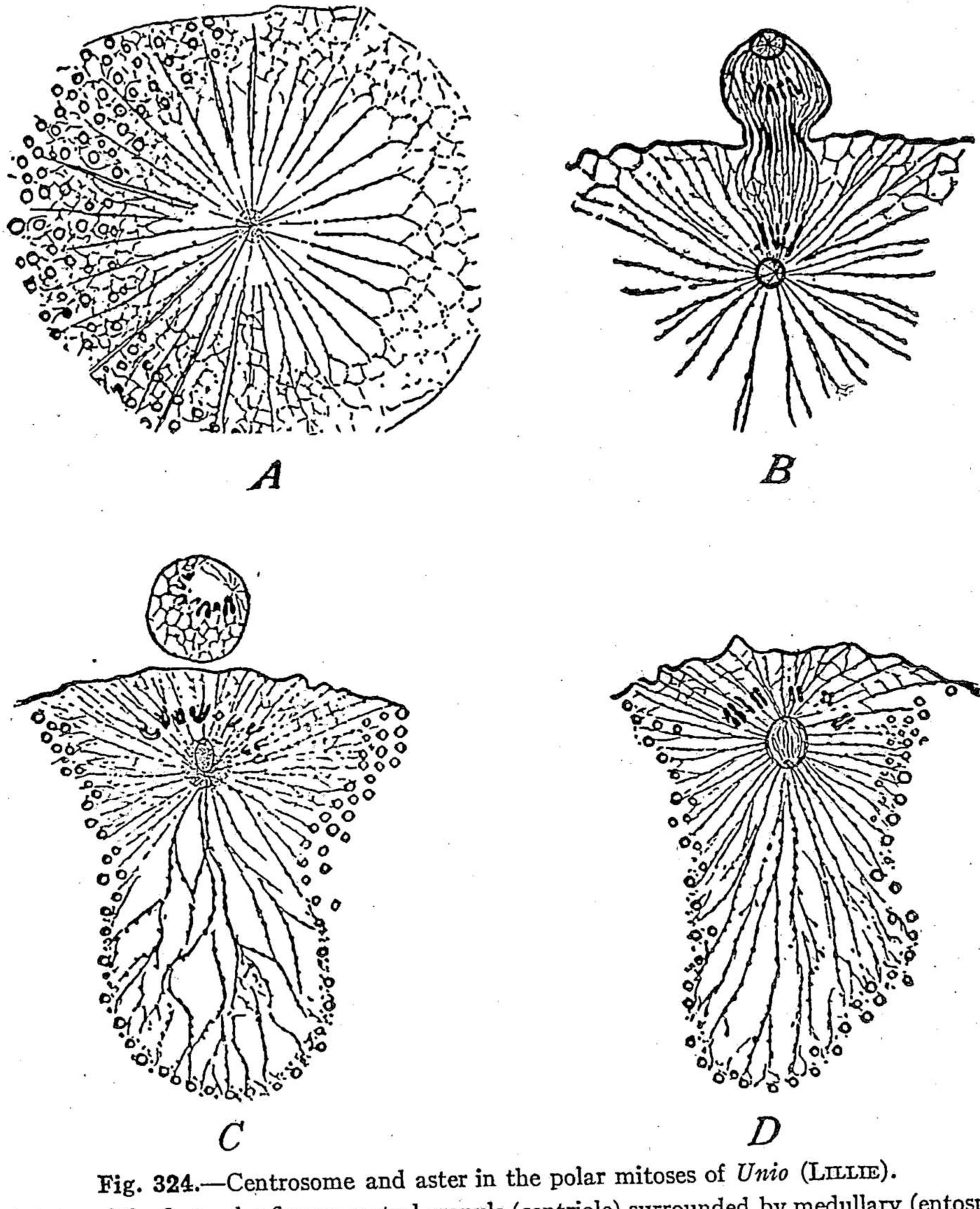

Fig. 324.—Centrosome and aster in the polar mitoses of *Unio* (LILLIE).

A aster of the first polar figure; central granule (centriole) surrounded by medullary (entosphere) and cortical (ectosphere) zones; *B*, late anaphase of second polar mitosis; radial entosphere bounded by continuous membrane; *C*, *D*, prophases of second mitosis; formation of central spindle within and from the substance of the old entosphere.

Growth of the centrosome continues throughout the whole mitotic process up to the late anaphase or early telophase, when in some cases it attains an enormous size, particularly in cells richly laden with yolk, such as segmenting eggs (Figs. 322, 330).

At its highest development the centrosome is of several different types, as follows:

(1) In the simplest case (Figs. 321, B, 323, 327) it is a spheroidal body of moderate size, homogeneous structure, and definite contour, and not traversed by the astral rays, which are inserted on its periphery. Examples of such centrosomes are offered by *Ascaris* as described in the cleavage of the egg by Boveri ('88, '01, etc.) and by Kostanecki and Siedlecki ('97), and in the spermatocytes by Brauer ('93).

(2) In a second type (Figs. 321, G, 58) often seen in the eggs of sea-urchins (Wilson, '01a, etc.), the centrosome offers a similar appearance but contains

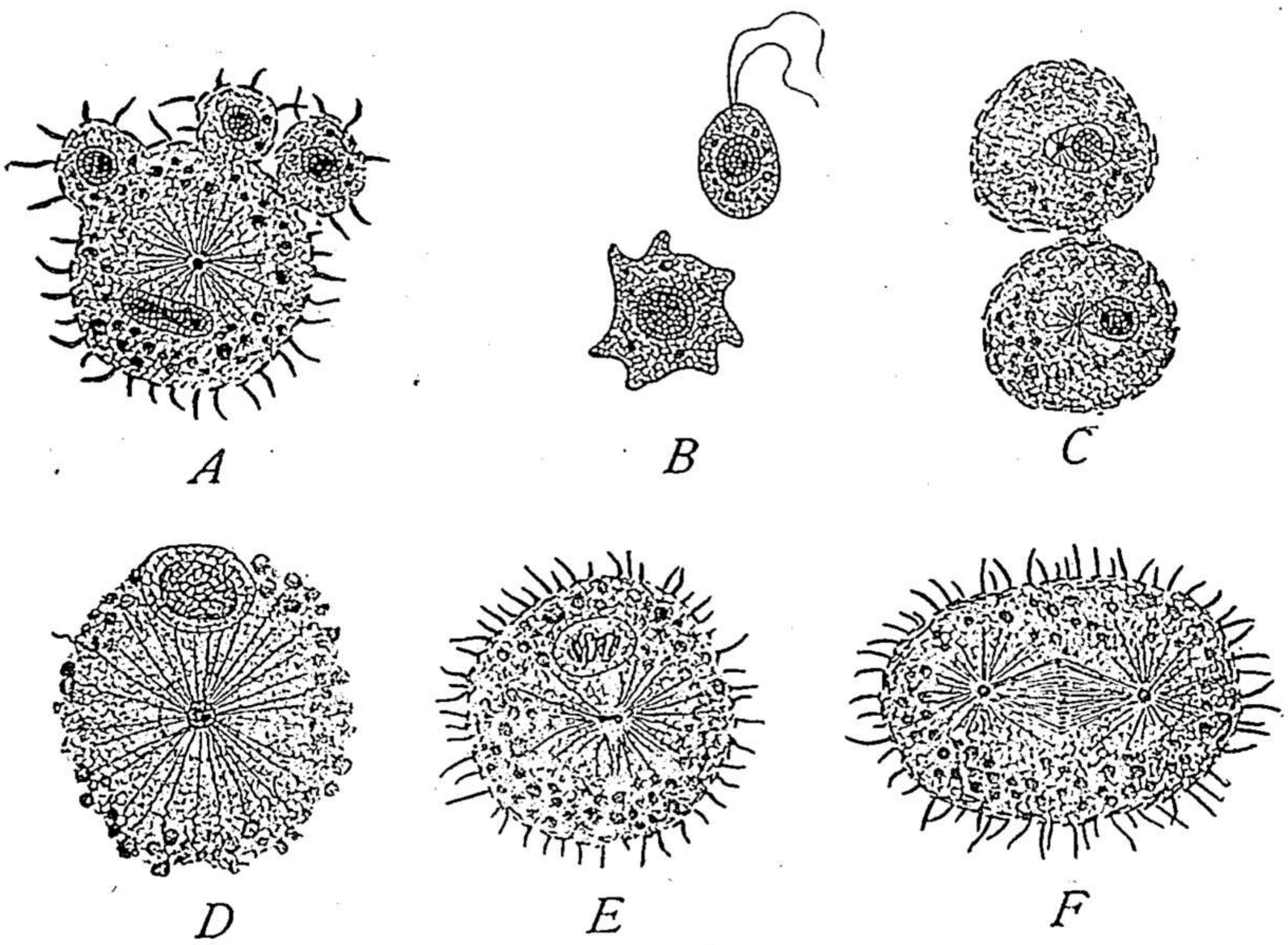

Fig. 325.—Central body (centroplast) in Heliozoa (SCHAUDINN).

A, *Acanthocystis*, bud-formation, producing *B*, swarm-spores, devoid of central bodies; *C*, swarm-spores preparing for division, new central bodies arising from nucleus; *D*, vegetative cell of *Sphærastrum* with nucleus, central body and aster; *E*, division of central body in *Acanthocystis; F*, metaphase.

a group of irregular granules so as to give almost the appearance of a small nucleus in which the centrioles cannot be distinguished. These have been called "pluricorpuscular" centrosomes; but Boveri ('01) considers them as artifacts and gives a description of the centrosome in sea-urchins approaching that of the first type (Fig. 327).

(3) In a third type, exemplified in the polar divisions of platodes and molluscs (Fig. 321, D–F), the centrosome, or at least its outer zone, is traversed by the basal portions of the astral rays, so as to assume a radial structure. This type affords convincing evidence that the centrosome is to be regarded as the innermost zone of the aster.

(4) In a fourth type, well shown in the early cleavage-stages of annelids and nemertines (Figs. 205, 329, 330), the centrosome becomes greatly enlarged, shows a finely alveolar or netlike structure, and often has a somewhat vague boundary. In this enlarged condition it was early described by Vejdovský ('88) under the name of *periplast* (later *centroplasm*) and by many later observers was called by Strasburger's ('92) term *centrosphere* (Wilson, Mead, Coe, Griffin, Meves, etc.). It was, however, made clear in the extended works especially of Boveri ('01) and of Vejdovský and Mrázek ('03) that this term should give way to the earlier one, *centrosome*.[1]

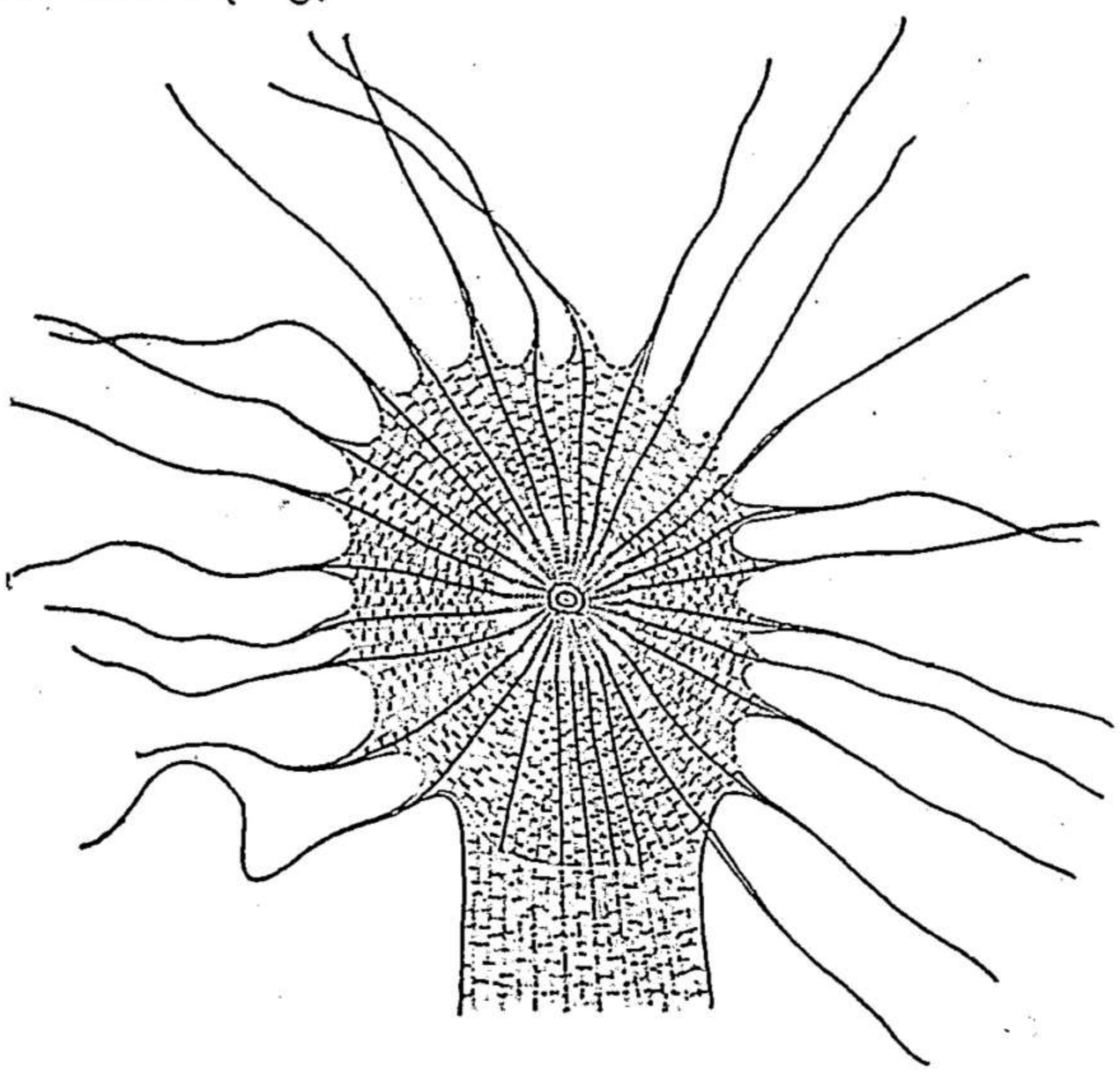

Fig. 326.—Astral system (pseudopods, axopodia, and central granule or centroplast) of the vegetative ("resting") cell in the rhizopod *Wagnerella* (ZUELZER). Basal granules of axopodia forming microsome-circle.

The above four types are connected by various intergradations, but their relations are not yet completely certain. The most probable view is suggested by the third or radial type, in particular the conditions in the *Ascaris* egg according to Van Beneden in his second paper published jointly with Neyt in 1887. The "central corpuscle" was here described as surrounded by two well-defined zones, each bounded by a very distinct ring of microsomes and traversed by astral rays (Figs. 76, 321, F). These zones obviously arise as differentiations of the inner region of the aster and were designated by Van Beneden respectively as "medullary" (inner) and "cortical" (outer), which together form the "attraction sphere."[2] Boveri considered his "centrosome" to be the equivalent of Van Beneden's "central corpuscle." Brauer ('93) suggested on the other hand that the central corpuscle was in reality the centriole and that *Boveri's "centrosome" corresponds to Van Beneden's "medullary" zone of the "attraction-sphere"*; and this view, adopted by numerous later observers, became the prevalent one. This conclusion sets aside the apparent anomaly offered by the fact that in the second type of mitosis (p. 148) the new amphiaster is formed *inside the old centrosome* (Fig. 47); for the centroplasm consists of the same material from which the old aster was formed. In some cases this zone is bounded

[1] See also Yatsu ('09).
[2] By Ziegler ('99), the two zones were called the *entosphere* and *ectosphere* respectively.

by a definite ring of microsomes; in others this ring later is transformed into an apparently continuous envelope (*e. g.*, Fig. 324), as in the second polar spindle of *Thysanozoön* (Van der Stricht) or of *Unio* (Lillie), and the facts seem to be similar in *Arion* (Fig. 328). In some cases the rays within this zone disappear, partially or wholly, (possibly in some cases as an effect of the reagents), thus giving the appearance seen in Type I. It is apparently the breaking up of these rays that gives rise to the large reticu-

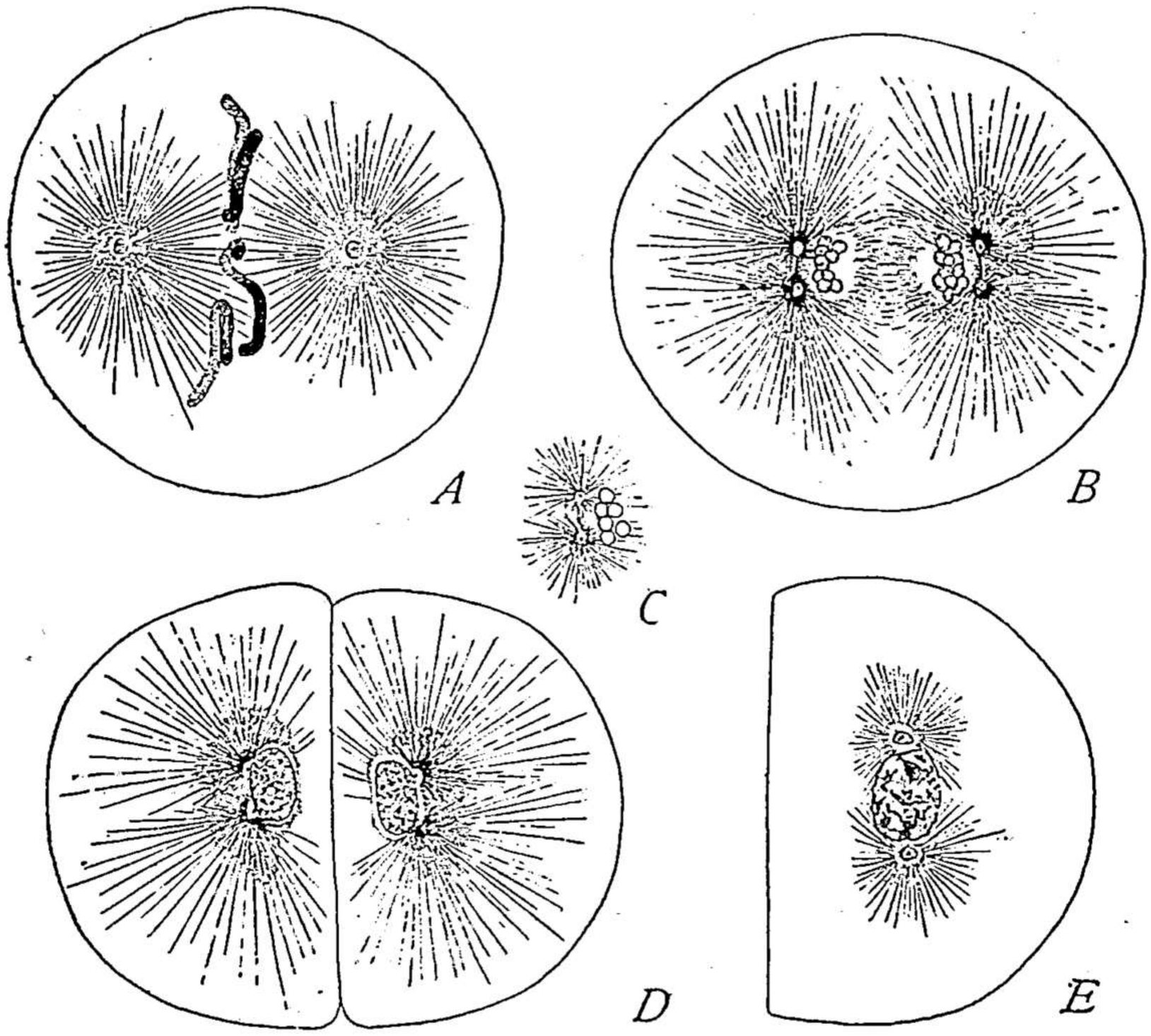

Fig. 327.—The central bodies during mitosis (BOVERI).

A, in *Ascaris megalocephala*, metaphase of first cleavage, centriole, centrosome and aster; *B–E*, in the sea-urchin *Echinus; B, C*, early telophase, karyomeres, division of centrioles; *D*, late telophase; *E*, "resting" stage.

lated or alveolar "centrosphere," "periplast" or "centroplasm" of the fourth type.

Van Beneden's "cortical zone," as Brauer pointed out, probably corresponds to the clear zone which in all four types is often seen surrounding the centrosome, sometimes without a definite boundary (sea-urchins, Fig. 58), sometimes sharply marked by a definite microsome circle (polar asters of *Unio*, Fig. 324). Some of these various conditions are show in the diagram, Fig. 321, which calls for no further explanation. Additional reason for accepting Brauer's comparison is perhaps given by the fact, that in some cases additional concentric microsome-circles seem to occur in the asters outside the clear zone; but the interpretation of this is still somewhat doubtful (p. 682). In any case the facts indicate that the particular

type of configuration in the centrosome is a matter of secondary importance, and that the centriole constitutes the most stable and constant feature of the whole astral system of which it forms the center.[1]

It is an interesting fact that the structure of the central apparatus and aster in higher forms is to a certain extent paralleled by the central granule and axopodial system in the heliozoan rhizopods. This may be seen in Schaudinn's figures of *Sphærastrum* (Fig. 325), in Dobell's of *Oxnerella* (Fig. 85) and still more clearly in Zuelzer's of *Wagnerella* (Fig. 326), in all of which medullary and cortical zones may be seen surrounding the central granule towards which the axopodia converge, the cortical zone bounded by a ring of microsomes. When we consider that the astral systems and central granules here play the same rôle during division as in the mitosis of higher forms (p. 203) we must admit that the conception of the amphiastral system as a fibrillar structure, and even as a contractile structure, may not be as baseless as some modern students of mitosis have assumed (p. 184).

2. Division of the Centers and Astral System

The centrosome and aster present certain further complications that may best be considered in connection with the division of the centers generally. The amphiaster was formerly supposed to arise by the division of a single mother-aster following division of the central body; and this led to attempts to follow out Rabl's early conception (p. 829) by the assumption that division of the center initiated a splitting of the astral rays and hence a meristic division of the whole aster; hence the aphorism *omnis radius e radio*.[2] This assumption proved to be erroneous and the division of a single aster into two was found to be a relatively rare process.[3] In most cases the old aster degenerates and the amphiaster appears as a new formation within its remains, even while the old aster is at the height of its development (Figs. 322, 328).

Many variations of this process have been observed.[4] In the most typical cases (*e. g.* in *Thysanozoön* or *Arion*) the young amphiaster is of quite typical structure, having a central spindle and asters whose rays show the usual equatorial crossing. Since this whole structure is formed inside the enlarged but still intact centrosome, the new astral rays and spindle-fibers, obviously, are differentiated from the centroplasm, and have *no*

1 For accounts diverging more or less from the above see Bonnevie ('06) (*Enteroxenos*), and Conklin ('01, '04, '05) (*Styela, Ciona* and especially *Crepidula*).

2 Kostanecki and Siedlecki ('97).

3 An undoubted example of such a division is offered by the division of the sperm-aster in the fertilization of the egg (p. 400).

4 These are reviewed by Yatsu ('09) in his paper on *Cerebratulus*.

direct relation to the old rays. As the process advances the old centrosome, continually enlarging, sooner or later loses its definite boundary, and the new astral rays now extend themselves more or less widely into the region of the old aster, while the latter sooner or later degenerates and disappears. The new asters, in such cases, are clearly new formations, not formed directly from the old ones but endogenously within them. Wide variations

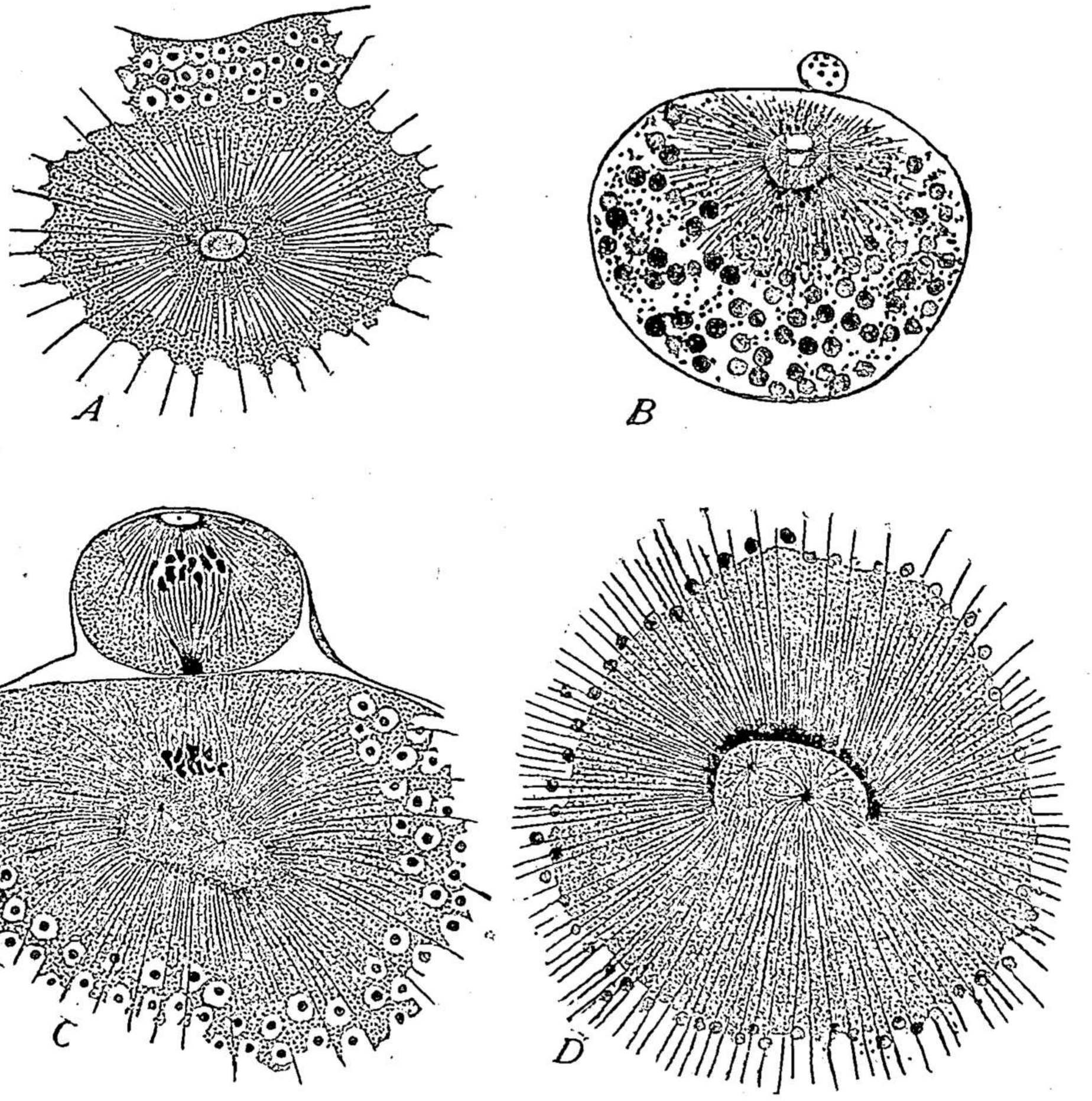

Fig. 328.—Structure of the asters and central bodies in the polar divisions of the egg. In each case the aster shown is the inner one of the first polar spindle (*A*, *C*, *D*, in the snail *Arion*, from LAMS; *B*, in the platode *Thysanozoön*, from VAN DER STRICHT).

A, polar view of aster at metaphase, early stage of new astral system; from the center outwards, (1) the centrioles; (2) centrosome (clear); (3), radiate cortical zone; (4) mitochondrial zone; (5) clear zone and (5) outer granular zone.

B, side view of inner aster, with daughter-amphiaster and medullary and cortical zones; *C*, *D*, telophases, breaking down of old centrosome, development of new astral system.

exist in respect to the details. In *Thysanozoön* (Van der Stricht) or in *Limax* (Byrnes) the new astral rays seem actually to traverse the microsome-circle that bounds the centrosome and to thread their way through the old rays outside it (Fig. 328). In *Arion* (Lams) the wall of the centrosome, here continuous, first dissolves at one side thus setting free the new

astral rays, which then become intermingled into the old ones (Fig. 328). In *Thalassema* (Griffin) the centrosome seems to lose its boundary at an early period and the new astral rays are intermingled with the old (Fig. 205). In *Rhynchelmis* (Vejdovský and Mrázek), where the centrosome assumes an enormous size, the original central spindle quickly disappears, and the two asters lie separately within the centrosome (Fig. 330). In all of these cases the two new centers and asters separate, and pass to opposite poles of the nucleus where they ultimately form the centers of the following mitosis (p. 438).

An important point, earlier noted (p. 148) is that in some of these cases—*e. g.*, in the trout (Henneguy), in *Cerebratulus* (Coe), or in *Thalassema* (Griffin)—the formation of the two new asters is preceded by a migration of

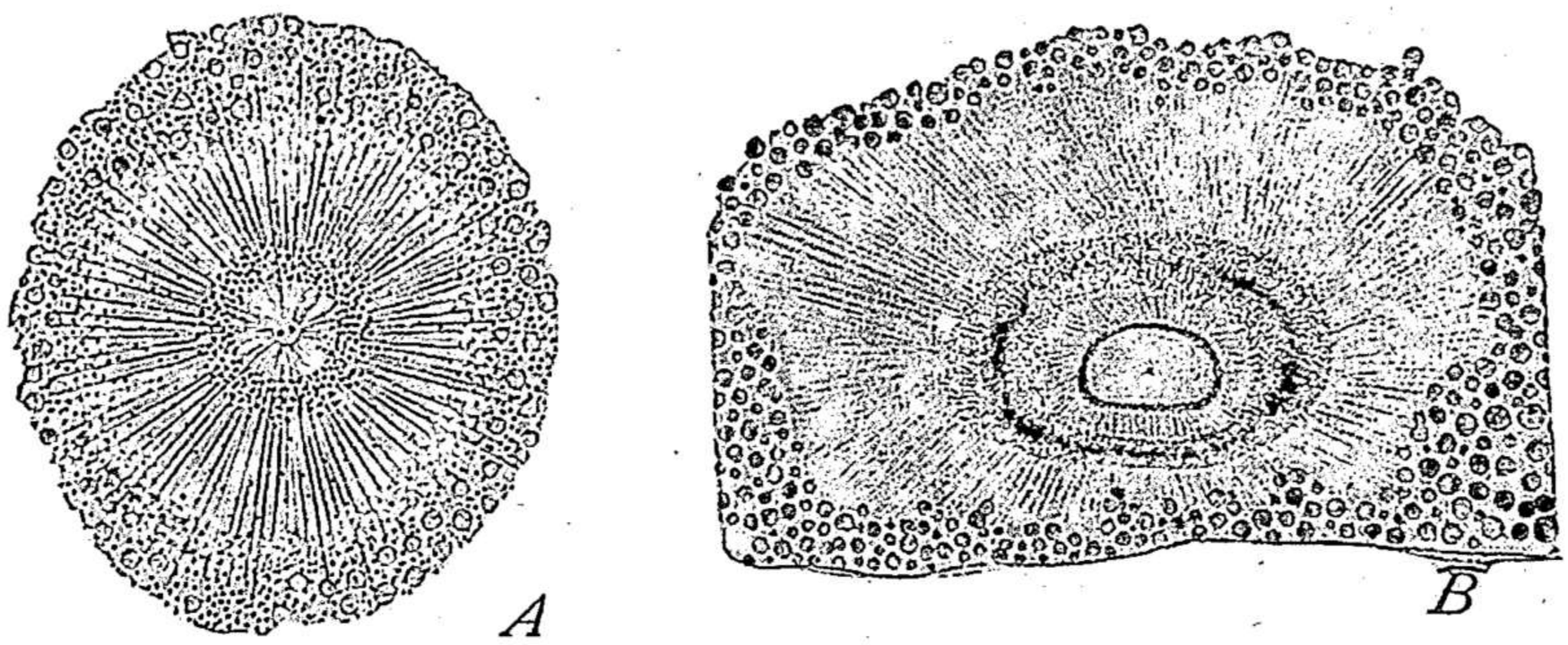

Fig. 329.—Structure of asters and centers.

A, inner polar aster in the egg of the snail *Arion* (Lams); *B*, aster from 4-cell stage of the annelid *Rhynchelmis* (Vejdovský and Mrázek).

In *A*, from the center outwards, (1) the two centrioles; (2) the clear centrosome; (3) the inner astral zone (= cortical layer of the "sphere"); (4) granular (mitochondrial) zone; (5) outer astral zone, (6) mitochondria and yolk.

In *B*, from the center outwards (1) centriole; (2) granddaughter-centrosome bounded by granular layer; (3) inner astral zone (cortical layer); (4) outer granular layer, marking boundary of earlier centrosome.

the centrioles towards the periphery of the centrosome, so that *the new astral system does not center in the old focus* (Figs. 205, 322). This affords evidence that the centriole is indeed an active division-center which causes the formation of the aster and is not itself created by the aster.

An interesting feature of the aster is the above mentioned fact (p. 146) that it sometimes shows more or less definite concentric zones outside the centrosome and clear zone. These were observed in *Ascaris* by Van Beneden, by Heidenhain ('92, '94) in giant cells and leucocytes (Fig. 10), by Braus ('95) in the segmenting eggs of *Triton*, and especially by Drüner ('94) in the spermatogonia of urodeles, in which no less than nine such concentric zones were found. By these authors the zoned appearance was believed to be due to the presence of concentric circles of microsomes upon the astral

rays; and such perhaps may sometimes be the case. The studies of Vejdovskŷ and Mrázek ('03) on cleavage in the annelid *Rhynchelmis* (Figs. 329, 330), and of Lams ('10) on the snail *Arion* (Fig. 329) seem to show that

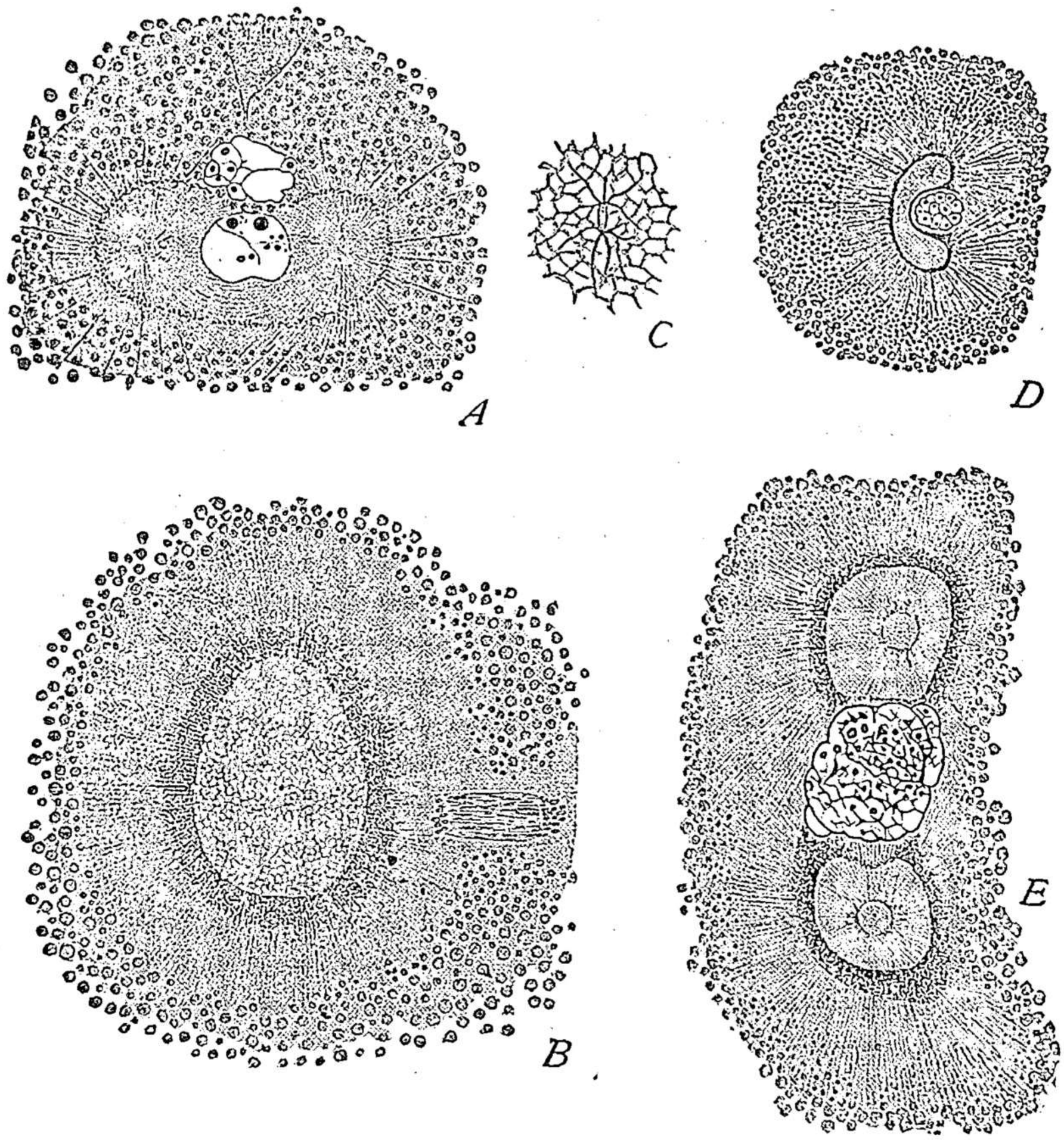

Fig. 330.—Relations of centers and astral systems in fertilization and first cleavage of the annelid *Rhynchelmis* (VEJDOVSKÝ and MRÁZEK).

A, conjugation of gamete-nuclei, prophase of first cleavage-amphiaster (sperm-amphiaster). At the center of each aster is a single centriole, surrounded by the clear second centrosome not traversed by astral rays. Outside of this the enlarged original centrosome (centroplasm) traversed by the astral rays and bounded by the dark granular zone; *B*, aster and spindle of early first cleavage-telophase (with karyomeres); centrosome greatly enlarged, granular zone (mitochondria) thickened; *C*, appearance of daughter-amphiaster within the old centrosome; *D*, resulting telophase-nucleus in 2-cell stage, division of daughter-centrosome; *E*, later stage of same, daughter-centrosomes enlarged and separate.

the appearance in question may be produced by a zoned massing around the centers, and between the astral rays, of other formed bodies (granules, etc.), the concentric zones thus produced being designated as *periplasms* or *centroplasms*. Vejdovský believes the zones to arise from the fact that after each division the peripheral portion of the old centrosome, continually enlarging and passing further away from the center, may

persist long after the daughter-centroplasms have formed within it, and even after a third generation has appeared within the second, a fourth within the third, and so on. The old centroplasms thus give the appearance of a series of concentric zones at the center of which lie the centrioles, and which are successively thrown off, as if by a process of "moulting" (Figs. 329, 330).[1] The interesting questions here raised await further elucidation.

Lastly the fact may again be recalled (*cf.* p. 30) that even in the "resting" cell, when the asters may be much reduced or even wanting, the central bodies are sometimes surrounded by zones of specific cytoplasmic bodies, such as the chondriosomes, Golgi-bodies, yolk-granules, etc. This fact, strikingly shown in the growth-period of the auxocytes (p. 329) bears witness to the importance of the central bodies considered as factors in the non-mitotic activities of the cell.

3. The Supposed Origin of Central Bodies de Novo

Whether central bodies may arise *de novo* as well as by division is a difficult question. Very often they are lost to view in the interphase or non-mitotic phase of the cell, reappearing in the prophase of the ensuing mitosis as if created *de novo* out of the protoplasmic substance. A conspicuous example is given by the heliozoön *Acanthocystis*, where the central body persists as an extra-nuclear body through many generations but seems to disappear in the budding individuals, to be re-formed in the nuclei of the buds and subsequently extruded into the cytoplasm (Fig. 325). Again, in the process of fertilization, the egg-center disappears from view after the completion of maturation to be replaced, apparently, by one imported by the sperm (p. 440). It is possible in all such cases that the centers do not actually disappear, but are lost among the cytoplasmic granules or have become reduced to sub-microscopic size; but this is merely hypothetical. Fortunately, however, the question may be approached by experimental methods; and these have afforded important if not yet wholly conclusive evidence. Reference has earlier been made to the accessory asters or cytasters (Figs. 331, 335) sometimes formed in the prophases of normal mitosis or fertilization, and often in eggs dividing under the influence of various physico-chemical agents (p. 481). The cytasters (in artificial parthenogenesis) often contain very definite central bodies (Morgan, '96–'00), and, as may be seen, both in living eggs and in sections they may multiply by division (Wilson, '01a). Division of the cytaster is initiated by that of the central body, the formation of a central spindle and of a typical amphiaster (Fig. 333); and during mitosis the cytasters actually operate as centers of

[1] See Yatsu, ('09).

division though the cleavage-furrows formed around them often are not permanent (Fig. 332). These facts indicate, if they do not prove, that the central bodies within these asters are true division-centers; and, since they are often seen developing simultaneously and independently in large numbers in all parts of the egg, that they are formed *de novo*.

This conclusion could not safely be drawn from such evidence alone; for the cytasters might result from a very rapid multiplication of a single

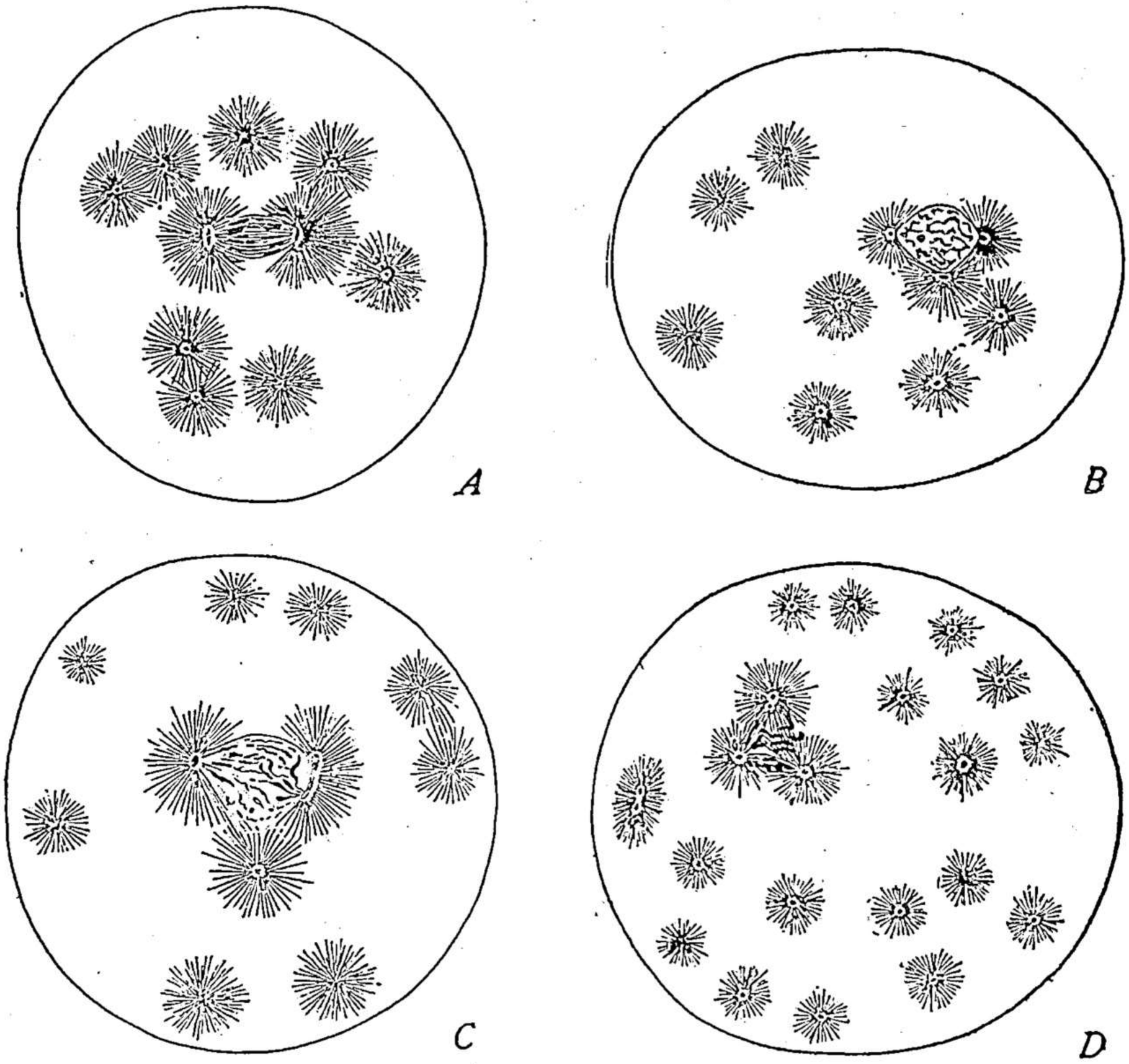

Fig. 331.—Cytasters in the artificial parthenogenesis of *Toxopneustes*, after treatment with hypertonic sea-water.

A, dicentric cleavage-figure in anaphase, cytasters and cyto-amphiasters; *B*, earlier stage, early tripolar figure; *C*, slightly later stage, following last; *D*, tripolar figure, cytaster dividing at left.

original egg-center, either before or subsequent to the development of the astral rays.[1] A crucial experiment was, therefore, attempted by shaking unfertilized eggs to pieces and treating the fragments with the same agent (sea-water rendered hypertonic by the addition of $MgCl_2$) that calls forth the production of cytasters in entire eggs. Under this treatment the *egg-fragments, whether nucleated or non-nucleated, were found to develop cytasters which are capable of multiplication by division, and which contain*

[1] Such a mode of origin was in fact afterwards maintained by Meves ('02), Wassilieff ('02), Petrunkewitsch ('04), and Buchner ('11); but on insufficient grounds.

central bodies (Wilson, '01a). Single cytasters may be formed in fragments as small as 1/150 the volume of the entire egg, but the cytasters only divide in larger fragments. Their history in the enucleated fragments as observed in life, is closely similar to that in entire eggs; the cytaster moves towards one side, elongates, its rays become much reduced, the hyaloplasm sphere at its center assumes an hour-glass shape, and the whole aster then divides

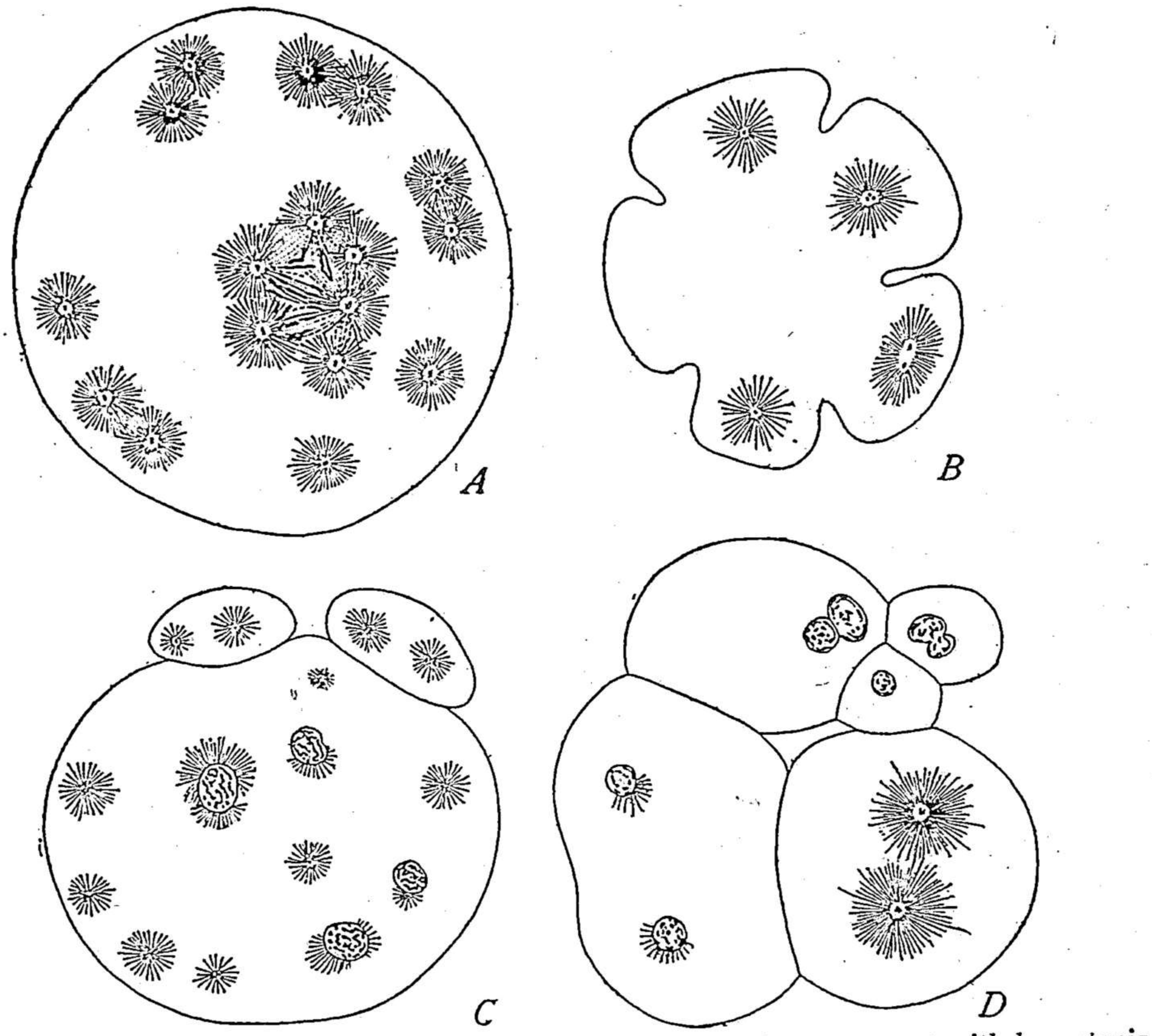

Fig. 332.—Cytological phenomena in the eggs of *Toxopneustes* after treatment with hypertonic sea-water.

A, polycentric figure, cytasters and cyto-amphiasters; *B*, tangential section at the time of first cleavage, showing furrows between cytasters; *C*, syncytial cleavage-stages showing complete cleavage about cytasters; *D*, abnormal cleavage-stage with cytasters in non-nucleated blastomere.

into two (Fig. 333). In these experiments *such enucleated fragments, despite the division of the aster*, never showed any sign of cytoplasmic cleavage. In entire eggs, however, one or more of the cytasters may come into association with the nuclear asters to form a triaster or polyaster, and in such case multipolar cleavage may take place (Fig. 332). From all these facts the conclusion was drawn that in their fullest development the cytasters are not to be distinguished from cleavage-asters either structurally or functionally; that the central bodies ("centrosomes") are true division-centers of the

same nature as those of entire, normal eggs; and that these bodies are formed *de novo* from the protoplasmic substance.

A confirmation of these results was given by the works of Yatsu ('05) and McClendon ('08) which exclude certain possibilities of error in the mass-cultures. Yatsu operated with the eggs of the nemertine *Cerebratulus lacteus*, which, upon discharge into the sea-water, and *without fertilization*, form the first polar spindle; and this remains in the metaphase-stage until

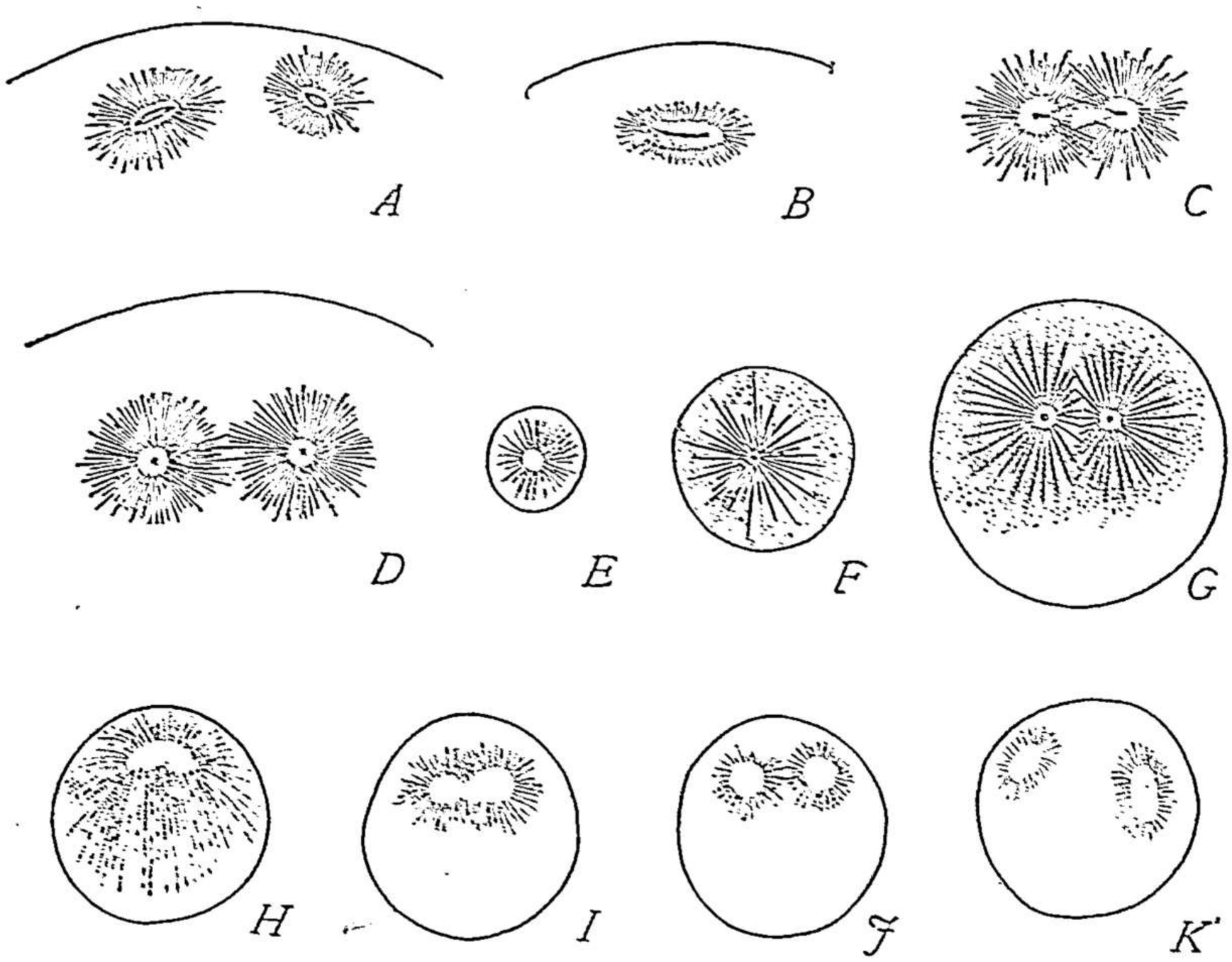

Fig. 333.—Division of cytasters in artificial parthenogenesis from entire eggs and egg-fragments of *Toxopneustes*.

A–C, various stages of division, from peripheral region, sections of entire eggs; *F*, *G*, from sections of enucleated egg-fragments; *E*, cytaster in very small living egg-fragment; *H–K*, successive stages in the division of a cytaster in a single, living, non-nucleated egg-fragment, elapsed time 25 minutes.

fertilization (p. 403). In this condition the eggs may readily be cut in two individually with a scalpel [1] and both fragments isolated for further observation. If the nucleated fragment be fixed and stained it is easy to demonstrate in it the presence of the polar spindle, at the poles of which are the two normal polar asters and central bodies (Fig. 334). On the other hand, the enucleated fragment, when treated with a parthenogenetic agent (in this case a solution of $CaCl_2$ in sea-water), readily develops a varying number of cytasters in all respects like those seen in the entire egg (Fig. 334). In some cases they are scattered through the fragment, in others occur only in a central large clear area. They show typical astral rays and a rather large and irregular centrosome or centroplasm within which is a group of

[1] Wilson, '03.

centrioles forming a pluricorpuscular center. No evidence of division was found in these asters or their centers.

In this experiment, obviously, the cytasters and their central bodies must have arisen without connection with the original egg centers; *i. e.*, they must have been formed *de novo*. Some doubts arise as to whether these cytasters are of the same nature as the corresponding ones in normal eggs because of the fact that the centrioles are multiple and that neither they nor the asters were found to divide; but this condition may very well be an effect

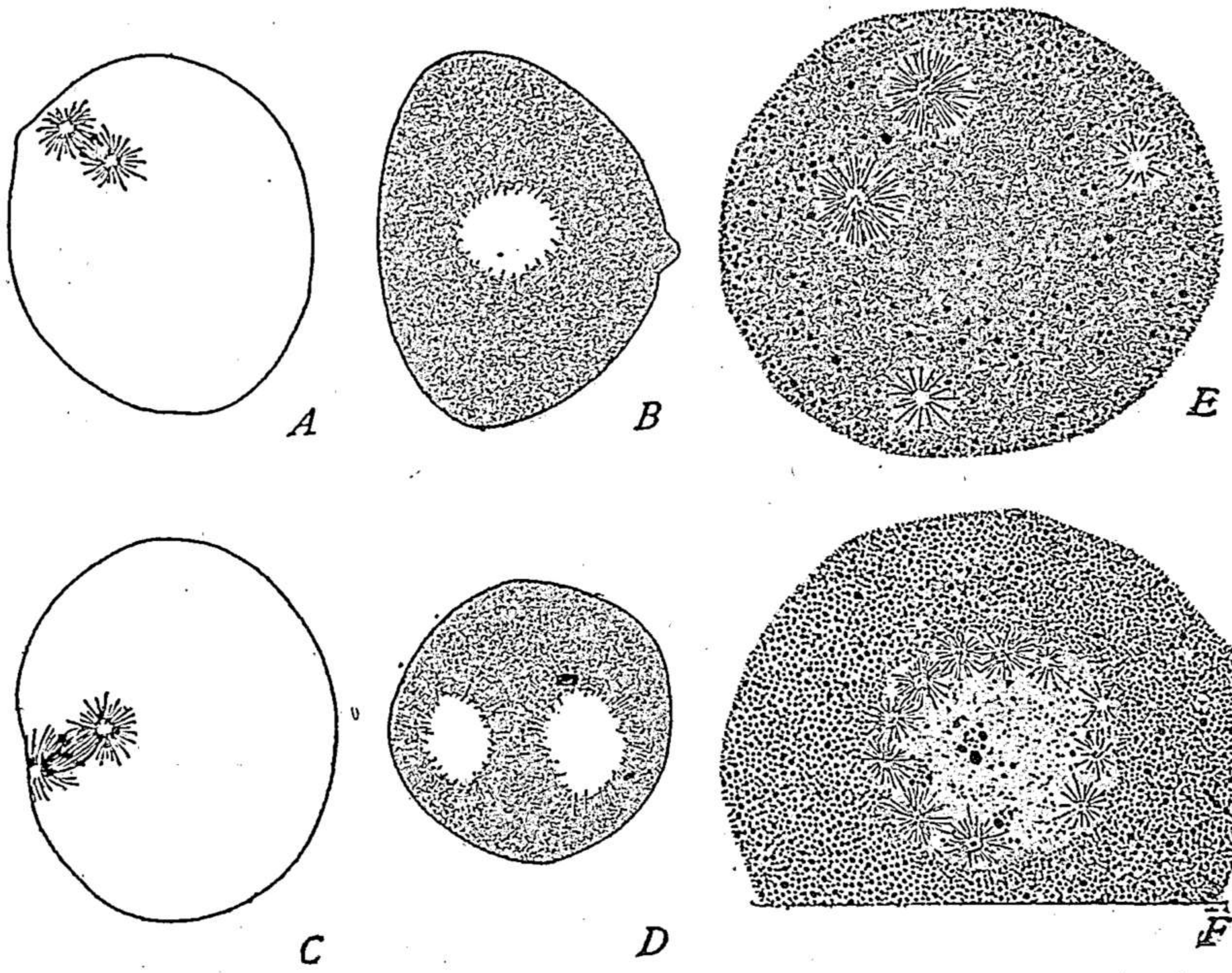

Fig. 334.—Formation of cytasters and centers in enucleated egg-fragments in the nemertine *Cerebratulus* after treatment with hypertonic sea-water (YATSU).

A and *B*, nucleated and non-nucleated pieces of a single egg cut in two with scalpel; *A* the nucleated half; *D* the non-nucleated, with large aster; *C*, *D*, similar pair from another egg; *E*, fixed and stained section of a non-nucleated piece, with four cytasters; *F*, section of a non-nucleated fragment showing central clear area with numerous cytasters.

of the reagent, since the same is seen in the polar asters of entire eggs after the same treatment, while in the writer's experiments the cytasters likewise often failed to divide. In the case of starfish eggs (*Asterias*) McClendon ('08), was able to suck out the polar spindle by means of a capillary pipette and then treated the enucleated egg with carbonated sea-water (Delage's method). Such eggs, deprived of both centers and chromatin, developed numerous cytasters, about which appeared cleavage-furrows and finally complete cleavage. Thus were formed non-nucleated "cells" devoid of nuclei, each containing one or more cytasters; and such "cells" were seen subsequently to divide again into two or more "cells." More recently

Herlant also ('18, '19) has been led to the conclusion that the cytasters are formed *de novo* and that one of them joins with the "nuclear aster" to form a synthetic amphiaster. In view of the difficulty of determining this point by direct observation the writer is, however, disposed to lay greater weight on the evidence derived from egg-fragments.

Unfortunately the foregoing experiments are not completely demon-

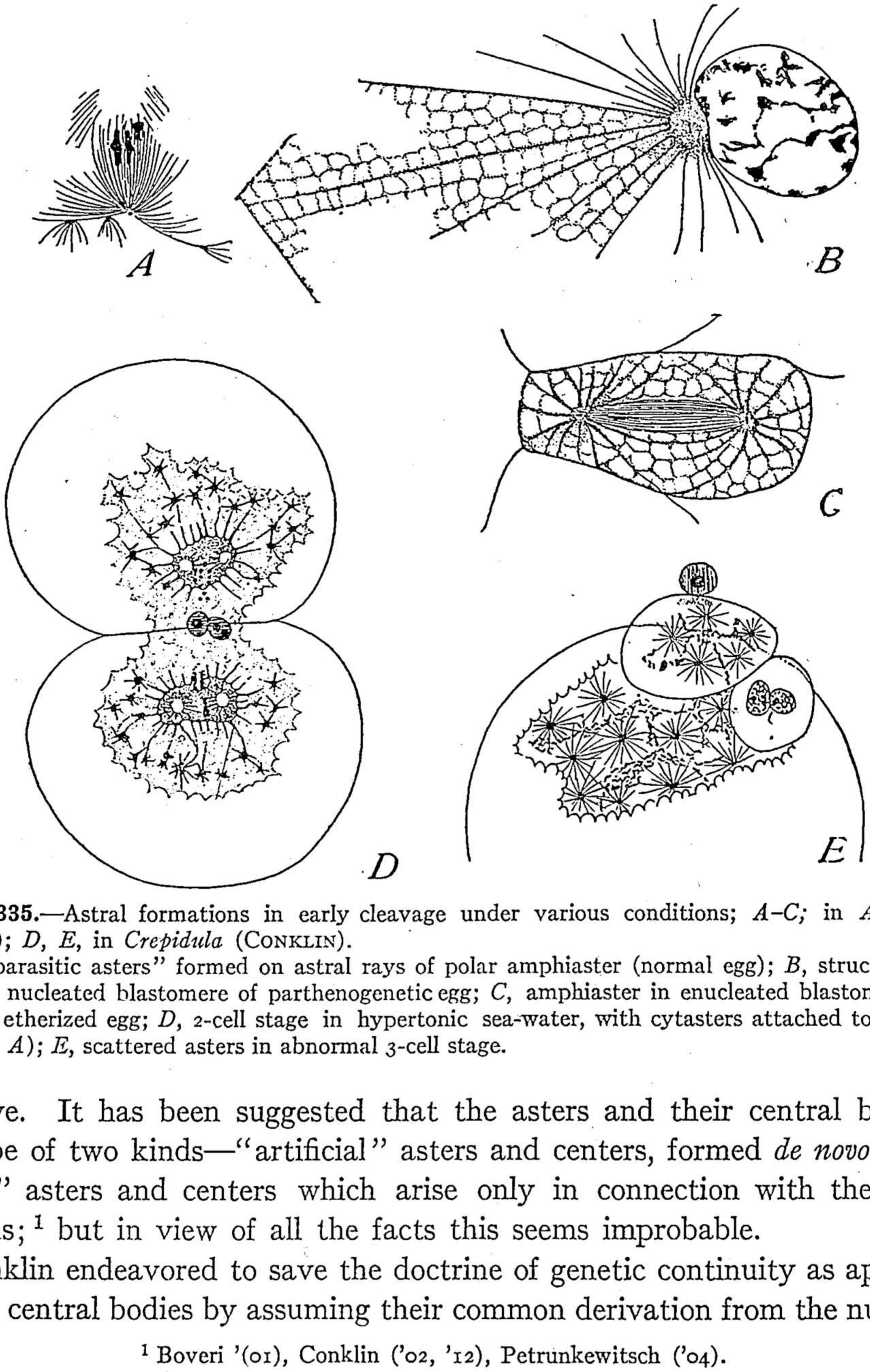

Fig. 335.—Astral formations in early cleavage under various conditions; *A–C;* in *Asterias* (YATSU); *D*, *E*, in *Crepidula* (CONKLIN).

A, "parasitic asters" formed on astral rays of polar amphiaster (normal egg); *B*, structure of aster in nucleated blastomere of parthenogenetic egg; *C*, amphiaster in enucleated blastomere of slightly etherized egg; *D*, 2-cell stage in hypertonic sea-water, with cytasters attached to astral rays (*cf. A*); *E*, scattered asters in abnormal 3-cell stage.

strative. It has been suggested that the asters and their central bodies may be of two kinds—"artificial" asters and centers, formed *de novo*, and "true" asters and centers which arise only in connection with the egg-nucleus;[1] but in view of all the facts this seems improbable.

Conklin endeavored to save the doctrine of genetic continuity as applied to the central bodies by assuming their common derivation from the nuclear

[1] Boveri '(01), Conklin ('02, '12), Petrunkewitsch ('04).

substance. As earlier indicated, a non-nucleated egg-fragment acquires the power to develop a sperm-aster only when the egg has been cut in two subsequent to the dissolution of the nuclear wall (p. 405); and Yatsu ('05) added the fact that when unfertilized egg-fragments (of *Cerebratulus*), thus obtained, are treated with hypertonic sea-water cytasters do not appear in the non-nucleated pieces unless the germinal vesicle has at least begun to break down prior to the operation.

This abundantly proves that "ripening" of the egg is due to the escape of material from the germinal vesicle, and that the presence of this material in the protoplasm of enucleated fragments is necessary for the development of cytasters and of the central bodies which they contain; but it offers no evidence that this material is a preëxisting "archiplasm," or that central bodies are formed from it. Were such the case, the doctrine of genetic continuity could only be saved by the proof that this material is actually derived from the central bodies or asters of a preceding mitosis; and were even this proved, the fact would remain that the central bodies of the cytaster, considered *as visible individualized structures*, are formed *de novo*, not by the division of preëxisting bodies of the same kind.[1]

4. The Central Bodies, Blepharoplasts, and Basal Apparatus

As earlier indicated, the function of the central bodies is not confined to the part which they play in mitotic division. They also may be concerned with the formation of cilia and flagella and with the more complicated basal apparatus often associated with the latter structures. Cilia and flagella, as is generally agreed, are but different modifications of a single type and are connected by many intergradations. A flagellum typically consists of a delicate *axial filament* surrounded by a protoplasmic sheath which typically disappears at a certain distance from the tip, leaving the naked terminal part of the axial filament as an *end-piece*. This condition, conspicuously shown in the animal sperm, has also been found in the flagellated Protista, *e. g.*, in *Euglena* (Bütschli), *Trachelomonas* (Plenge), or *Bodo* (Fischer), and is probably of general occurrence. The internal structure of cilia is more difficult to analyze, owing to their extreme tenuity; nevertheless the presence of an axial filament and a surrounding sheath seems to have been clearly demonstrated in certain cases.[2] At the base of the axial

[1] A possible source of error in some of these experiments is indicated by Boveri's posthumous work ('18) in which it is shown that when eggs are shaken to pieces the nuclei are readily altered or even disorganized, so that it may be impossible to distinguish certainly between nucleated and non-nucleated fragments; all results based on this method, therefore, require further evidence. Such an error is eliminated by cutting experiments on individual eggs (as in Yatsu's experiments). In the writer's judgment, therefore, the origin of true central bodies or division-centers *de novo* has been rendered at least probable; but the questions here involved are too fundamental to be accepted unreservedly without additional proof.

[2] See Maier ('03), Koltsoff ('06, '09), Erhard ('10), Khainsky ('10), Saguchi ('17), etc.

filament is a *basal apparatus* consisting in its simplest form of a single basal body (Fig. 341) but often of much greater complexity.

Both cilia and flagella, as a rule, are secondary and often temporary structures, though in certain flagellates they may actually divide by longitudinal fission and thus be handed on from one cell-generation to another (Fig. 336). The axial filament originally grows forth from a basal body or blepharoplast which in some cases plays the part of a division-center during mitosis

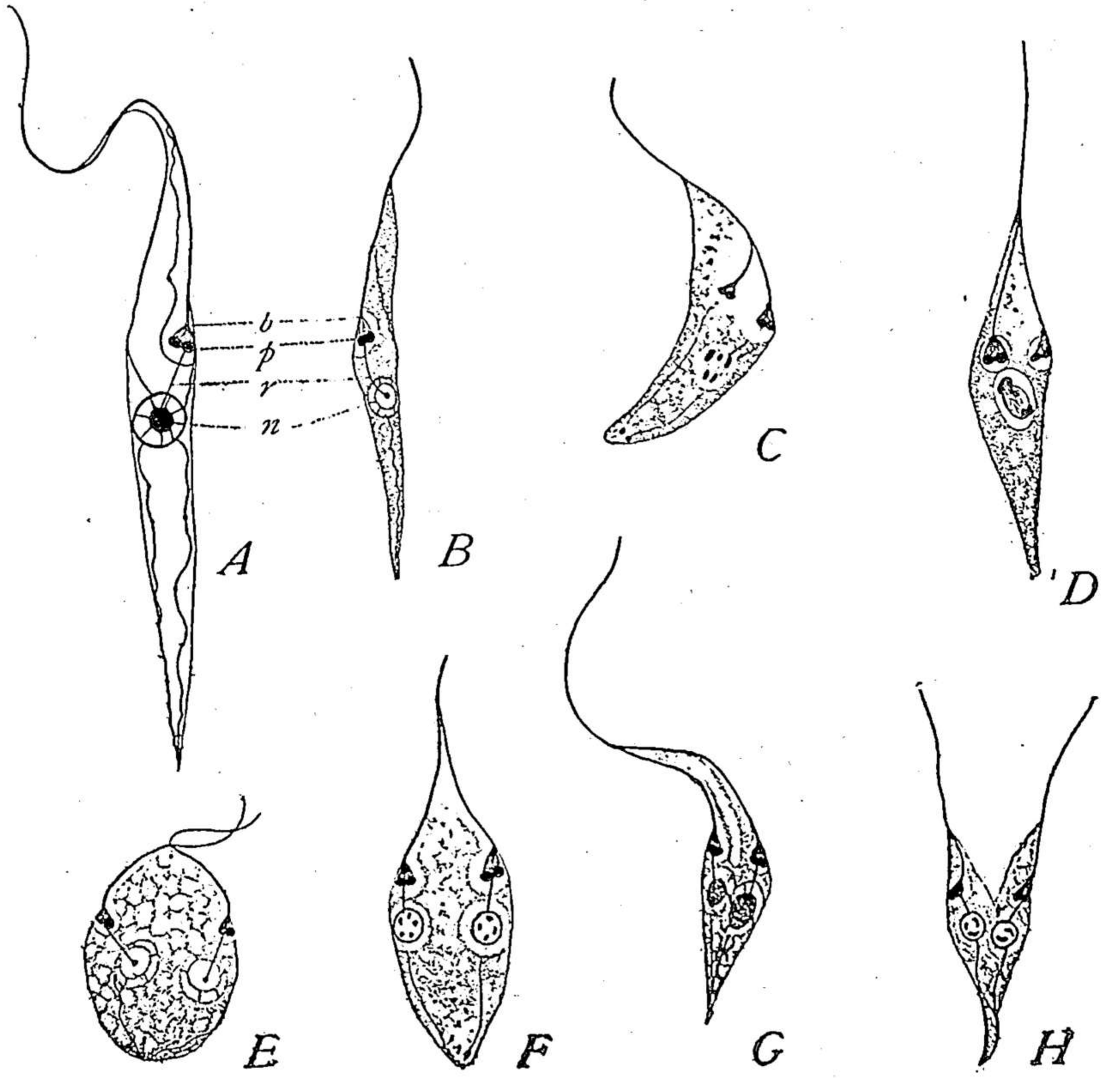

Fig. 336.—Basal apparatus and longitudinal fission in the flagellate *Crithidia leptocoridis* (McCulloch).

A, *B*, vegetative individuals; *b*, basal body or blepharoplast; *n*, nucleus; *p*, parabasal ("kinetonucleus"); *r*, rhizoplast; *C–H*, stages of fission, longitudinal fission of the flagellum, division of blepharoplast and parabasal without relation to the nuclear spindle.

and hence is identical with a centriole. This phenomenon is now conclusively established in the spermatogenesis of some animals and plants (p. 357) and among the flagellated Protista. In the latter case, however, a more complicated type of basal apparatus is often present, the blepharoplast being sometimes quite distinct from the centriole, while in addition a *parabasal* body and other structures may also be present. The relations between these various basal structures have not yet been completely elu-

cidated; and the same may be said of the basal bodies in the ciliates and ciliated tissue-cells of higher Metazoa. That a close analogy exists between all these various basal structures can harldy be doubted, but the morphological problems here involved still await adequate analysis.

a. Centriole and Blepharoplast in the Sperm-formation. In animal spermiogenesis it is probable that in all cases the centriole is the lineal descendant of the centrioles of earlier cell-generations, possibly even back to the fertilized egg. On the other hand, in higher plants (bryophytes, pteridophytes, cycads, *Ginkgo*) division-centers seem to be absent in both the somatic cells and in those of the earlier germ-line; nevertheless in the closing spermatogenous divisions the spindle-poles are occupied by blepharoplasts which in many cases show all the characteristics of division-centers, arising by the division of a single body and surrounded by astral rays, while a spindle forms between them. In this case, clearly, the law of genetic continuity as applied to these structures is of much more limited application, and the central bodies (blepharoplasts), considered *as individualized bodies*, must apparently be formed *de novo* at a certain late point in the germ-line (p. 387).

The fact has earlier been emphasized that in animal spermatogenesis the original spermatid centriole divides into two products of which only one (the distal) forms the blepharoplast, while the other (the proximal) has no direct connection with the axial filament (p. 381). Further, the distal centriole itself frequently divides into two portions, of which only one remains in connection with the axial filament while the other in the form of a ring or otherwise, undergoes a displacement varying widely in different species of sperms, and in some cases apparently is cast out altogether (p. 376). In these facts we find reason to conclude that the centriole itself may be a compound, or at least dual body, *of which only one component is concerned with the functions of a blepharoplast.* This is supported by facts in the flagellated Protista, now to be considered, which prove that centriole and blepharoplast may be completely separate structures.

b. The Basal Apparatus in Flagellated Protista. The basal apparatus of the flagella in Protista shows many interesting complications of which only a few illustrations can here be offered.[1] In its simpler forms the basal apparatus has been described as a single basal granule (blepharoplast), or a small group of such bodies, from each of which a flagellum grows forth; but in most if not in all cases other basal structures are associated with it. Typically it lies near the cell-periphery at the base of the flagellum (Figs.

[1] See Prenant ('14), Kühn ('15), Kofoid and Swazey ('15), Doflein ('16, '18), Swezy ('16), Kuczynski ('18), Bělař ('21).

337, 338), but often more deeply, sometimes near the nucleus or even within it. In the amœbo-flagellate *Nägleria* the basal granule is said to be originally within the nucleus, apparently inside the karyosome, later escaping from it to form a blepharoplast from which the flagella grow forth (Fig. 337). Probably in all these various cases it gives origin peripherally to the axial filament of the flagellum. Centrally, a delicate fibrilla or rhizoplast extends

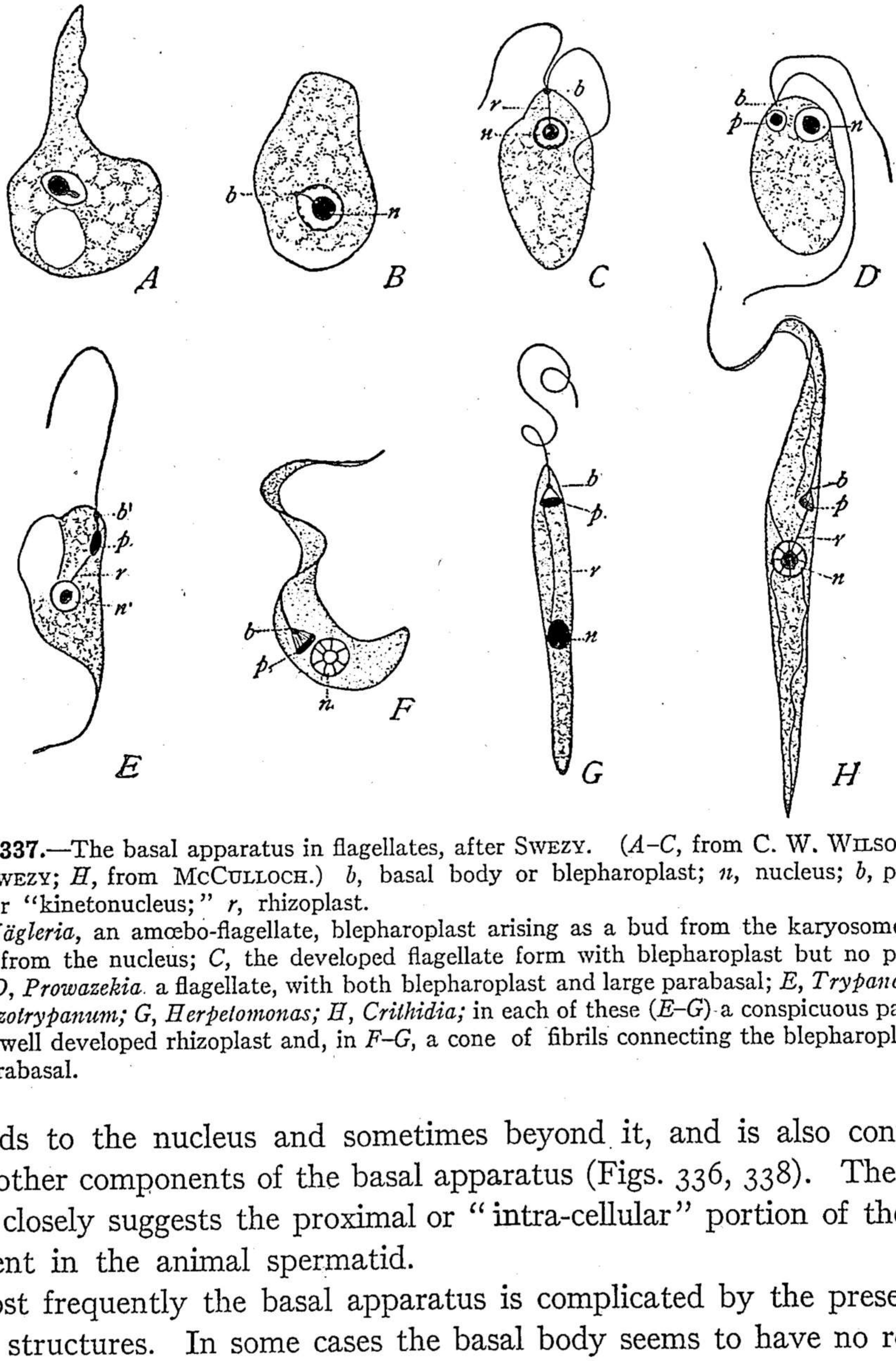

Fig. 337.—The basal apparatus in flagellates, after SWEZY. (*A–C*, from C. W. WILSON; *D-G*, from SWEZY; *H*, from MCCULLOCH.) *b*, basal body or blepharoplast; *n*, nucleus; *b*, parabasal body or "kinetonucleus;" *r*, rhizoplast.

A, *Nägleria*, an amœbo-flagellate, blepharoplast arising as a bud from the karyosome; *B*, its escape from the nucleus; *C*, the developed flagellate form with blepharoplast but no parabasal body; *D*, *Prowazekia*. a flagellate, with both blepharoplast and large parabasal; *E*, *Trypanoplasma; F*, *Schizotrypanum; G*, *Herpetomonas; H*, *Crithidia;* in each of these (*E–G*) a conspicuous parabasal, with a well developed rhizoplast and, in *F–G*, a cone of fibrils connecting the blepharoplast with the parabasal.

inwards to the nucleus and sometimes beyond it, and is also connected with other components of the basal apparatus (Figs. 336, 338). The rhizoplast closely suggests the proximal or "intra-cellular" portion of the axial filament in the animal spermatid.

Most frequently the basal apparatus is complicated by the presence of other structures. In some cases the basal body seems to have no relation to the division-figure while definite centrioles have in addition been de-

scribed in some cases at the spindle-poles (*e. g.*, in *Collodictyon* (Fig. 341) In addition to the foregoing there is often a larger and more conspicu ous *parabasal body* typically connected by fibrillæ (rhizoplasts) with both blepharoplast and nucleus. In a few cases this is said to be a tempo- rary structure, indistinguishable in certain phases of the life-history; but it is typically persistent, often being handed on by division like

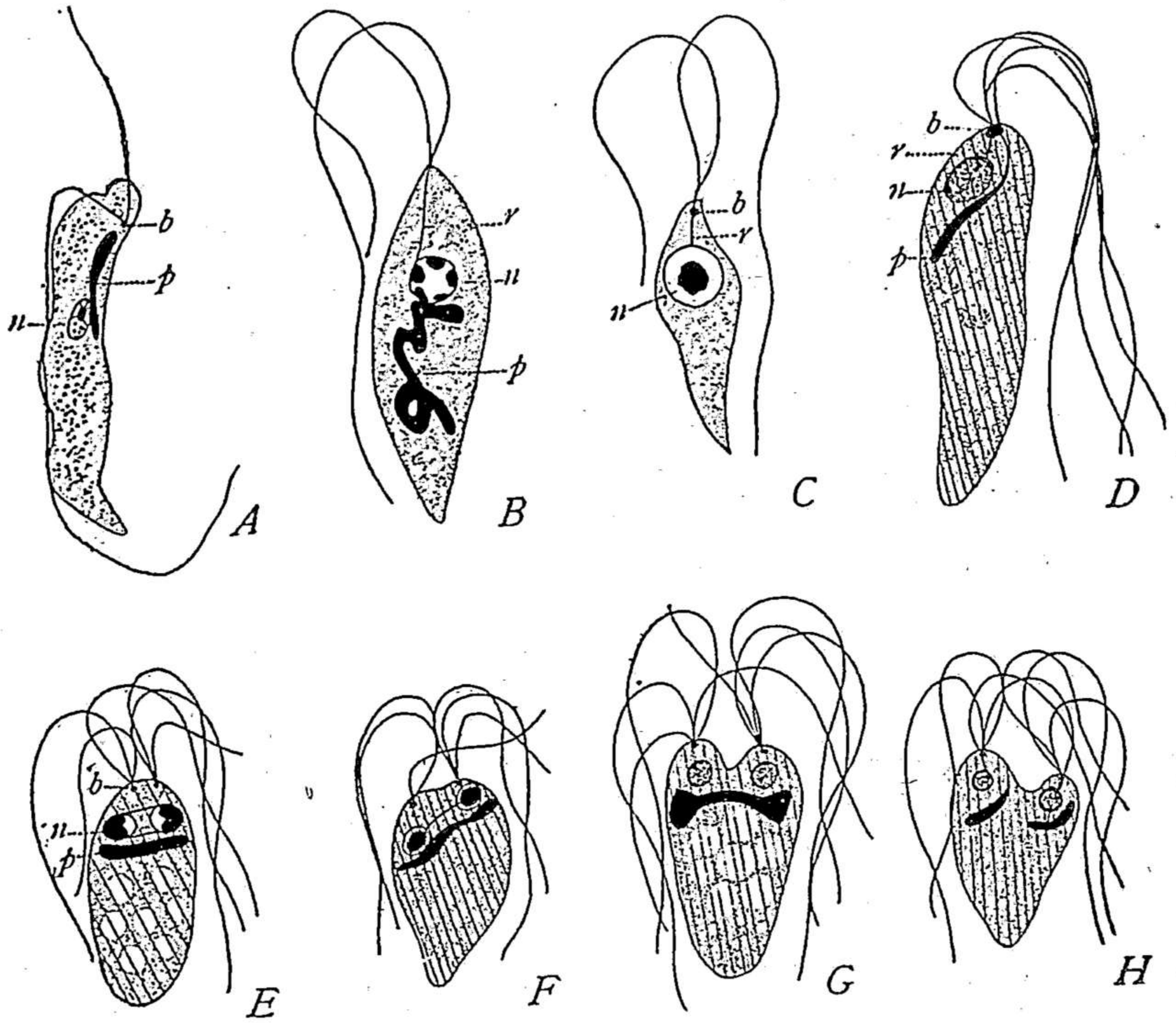

Fig. 338.—The basal apparatus in flagellates.

(*A*, from MARTIN; the rest from SWEZY.)

A, *Trypanoplasma; B*, *C*, *Prowazekia; D–H*, *Polymastix*. Small letters as in Fig. 337.

A, *B*, vegetative individuals (trophozoites) with large parabasal; *C*, individual without para- basal, ordinary trophozoite; *E–H*, stages of mitosis, division of both blepharoplast and parabasal independently of the nucleus.

the blepharoplast (Figs. 336, 338) and showing a great variety of forms. In some species it is a rounded body connected peripherally with the blepharoplast by a single fibrilla (*Trypanoplasma*, Fig. 337, E) or by a cone of such fibrillæ (*Herpetomonas*, *Crithidia*, etc., Fig. 336) and centrally by a single fibrilla with the nucleus, from which one or more such fibrillæ may also extend towards the basal region of the cell. In other cases it is a more or less elongate and sometimes convoluted rod. This structure, still of doubtful significance, has received many names (*chromidial body*, *reserve-body*, *blepharoplast*, etc.). By Schaudinn ('96–'03) and his successors, even to a recent date, it was called the "blepharoplast,"

and was regarded as a second nucleus or "kinetonucleus" (Woodcock, '06); and out of this grew the so-called "binuclearity theory" of the protistan cell (Hartmann, '07, '11) (p. 726).

More recent studies have failed to support this view, giving no evidence of the nuclear nature of the parabasal, pointing rather to the conclusion that it has arisen as a derivative of the basal body; further, that both bodies,

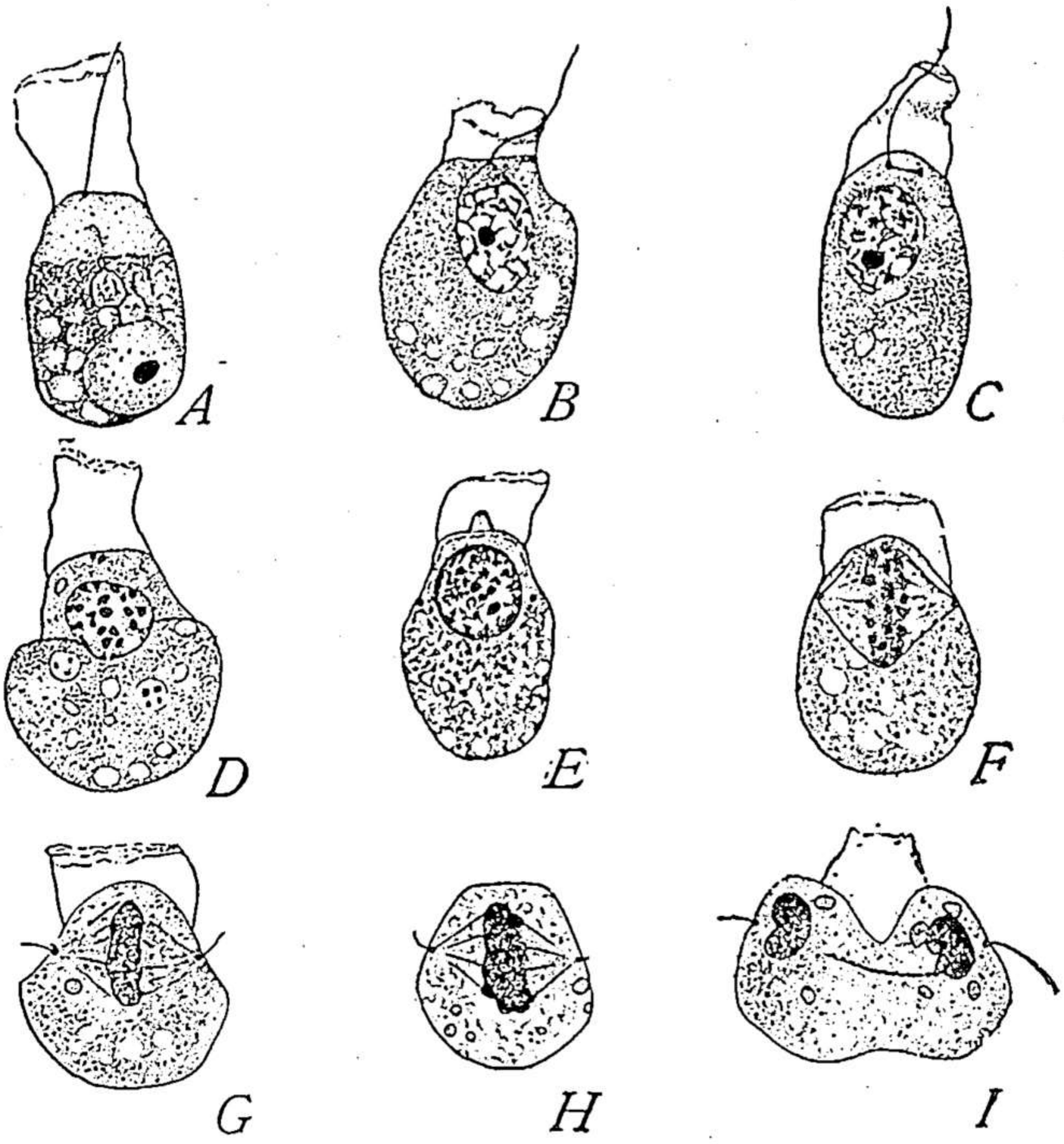

Fig. 339.—Mitosis of the choanocytes in the sponge *Clathrina* (MINCHIN).

A, *B*, vegetative cells; *C*, *D*, division of blepharoplast, disappearance of flagella; *E*, *F*, separation of blepharoplasts, spindle-formation; *G*, *H*, *I*, later stages of mitosis, outgrowth of new flagella.

together with the connecting rhizoplasts, belong to a "neuro-motor" apparatus [1] concerned with the motor activities as well as with the operations of division. This apparatus reaches its highest development in the ciliates, where it is sometimes of great complexity.[2] We are here concerned only with its relation to the phenomena of division, as yet definitely known only in the flagellates.

Still other structures, of unknown significance, may be found in connection with the basal apparatus. One is a basal ring of unknown origin, encircling the rhizoplast below the blepharoplast (Fig. 340) [3] which recalls the ring derived from the distal centriole in the spermatids of mammals and some other animals (p. 377).

[1] Kofoid and Christiansen ('15).
[2] Sharp ('14), McCulluch ('15), Yocom ('18), Taylor ('20).
[3] See Kuczynski ('18), Bělař ('21).

c. Blepharoplast and Centriole in Protista. The foregoing conditions may offer a clue to the fact that in some of the flagellates the blepharoplast seems to play the part of a centriole during mitosis while in others it is a quite distinct structure, not lying at the spindle-poles, but handed on by division from cell to cell. The contradiction disappears under the view that the centriole in some cases unites the functions of a division-center and a blepharoplast while in others the centriole has separated into two

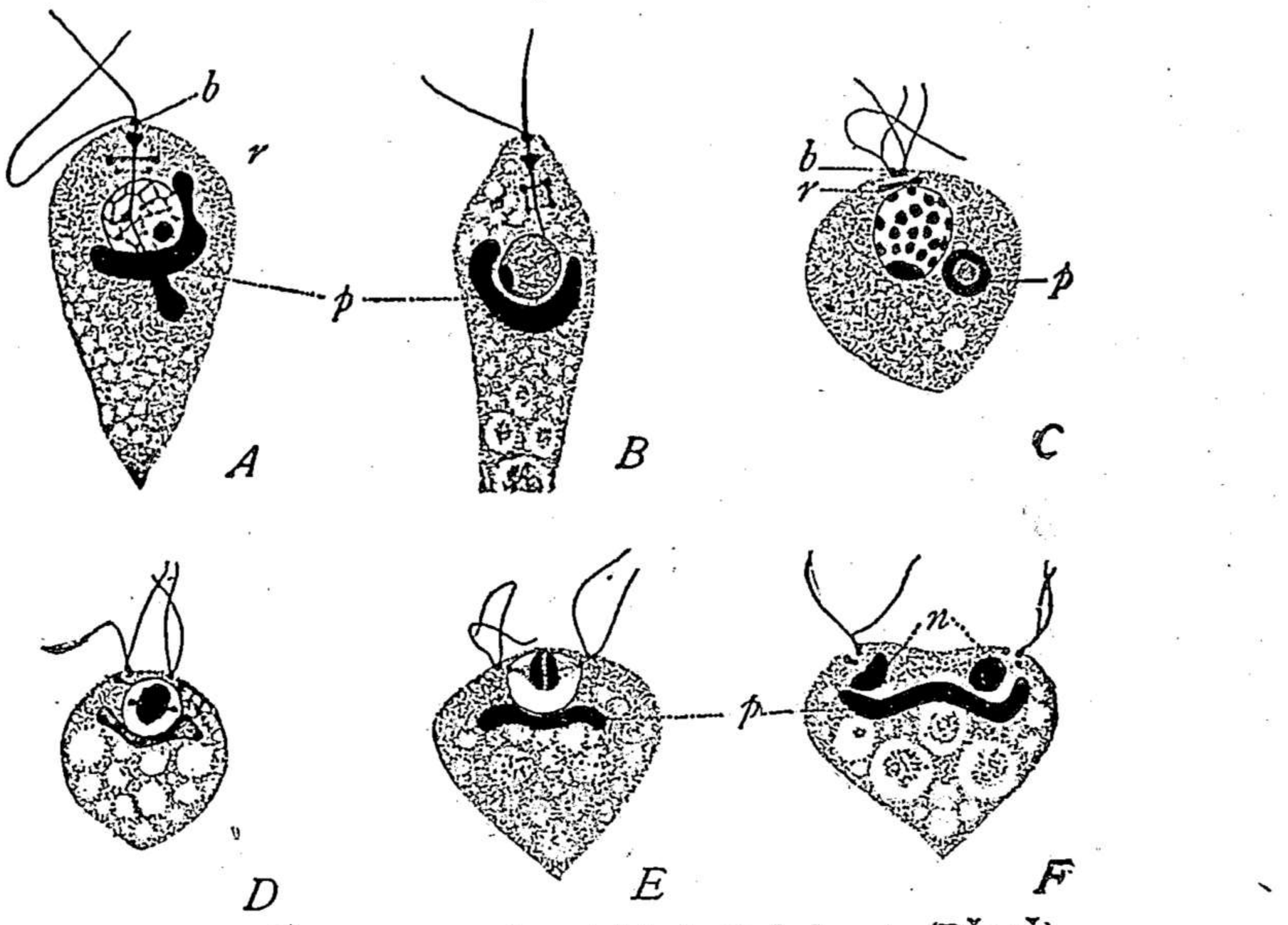

Fig. 340.—Basal apparatus and centriole in *Bodo lacertæ* (BĚLAŘ).

A, *B*, normal vegetative individuals, with blepharoplast (*b*), basal ring (*r*), and parabasal (*p*); *C*, initial stage of division; *D*, later stage, with supposed intra-nuclear spindle and centrioles; *E*, metaphase; *F*, telophase.

corresponding distinct structures. Examples of the first case seem to occur in species of *Bodo*,[1] *Copromonas*,[2] *Ochromonas* [3] and *Trichomonas;* [4] and similar conditions are described by Jahn ('04) in the flagellated swarm-spores of myxomycetes and by Minchin and Robertson ('10) in the collar-cells of calcareous sponges (Fig. 339). In some of these cases the old flagella disappear in the earlier stages of mitosis, new ones growing forth at a later period; in others the old flagella seem to persist throughout. In *Bodo lacertæ*, for example, Bělař found two basal bodies, close together and each bearing a single flagellum. As they separate in the prophases each divides into two parts, one bearing the old flagellum while a new flagellum grows forth from the other, the double blepharoplasts and flagella then persisting throughout

[1] Prowazek ('04), Alexeieff ('14), Kuczinski ('18), Bělař ('21).
[2] Dobell ('08).
[3] Doflein ('19).
[4] Kofoid and Swezy ('15), etc.

all the later stages (Fig. 340). In *Trichomonas* the facts are similar (Fig. 86) though somewhat more complicated. Upon division of the single blepharoplast two of the three free flagella remain attached to one half and one to the other, while the normal number is in each case restored by a new formation, as in *Bodo*. The fourth or intra-cytoplasmic flagellum is said to split lengthwise throughout, half remaining connected with each half of the blepharoplast.[1]

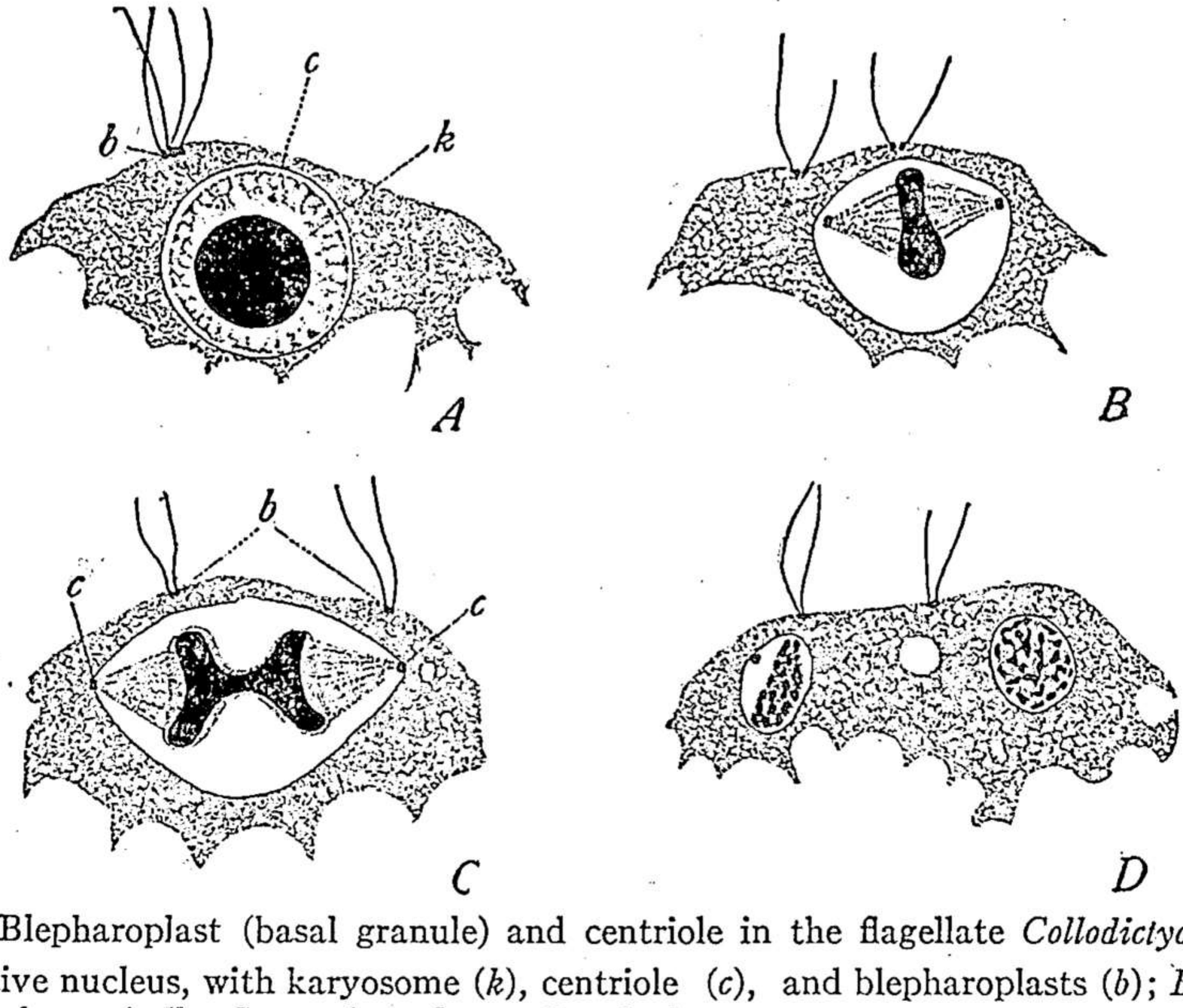

Fig. 341.—Blepharoplast (basal granule) and centriole in the flagellate *Collodictyon* (BĚLAŘ). *A*, vegetative nucleus, with karyosome (*k*), centriole (*c*), and blepharoplasts (*b*); *B*, metaphase with intra-nuclear spindle; *C*, anaphase figure; *D*, telophase.

The most conspicuous fact here is that during the whole process the blepharoplasts, still bearing their flagella, occupy the spindle-poles, as in case of the Lepidoptera; but there are two important additional facts. In *Trichomonas* several observers have found indications that the blepharoplast-centriole is a double body, at least in certain stages, the flagella being attached to one of these, while the other is connected with its fellow by the paradesmose (p. 204). Kofoid and Swezy, accordingly, consider these two components to represent, respectively, the blepharoplast and the centriole, here so closely associated as often to appear as a single body. Such a condition might readily lead into one in which the two components are wholly separate and divide independently. Bělař found that in *Bodo* the blepharoplasts are at first quite separate from the centrioles at the spindle-poles but later move towards the latter to a position just outside the centrioles (Fig. 340), later assuming their typical position at the cell-periphery,

[1] The latter observation by Kofoid and Swezy ('15) was not confirmed by Kuczinski ('18) and Wenrich ('21).

From such a condition it would be only a step to one in which the blepharoplasts divide and separate at the periphery without approaching the spindle-poles as in *Polytoma* (Doflein, '16), *Polymastix* (Fig. 338), *Crithidia* (Fig. 336), or *Collodictyon* (Fig. 341).

Swezy ('16) has developed in an interesting way the view that the whole basal apparatus has developed by the growth and differentiation of a simple original basal granule comparable with the centriole-blepharoplast of higher forms. That a body originally so minute should be capable of producing an apparatus of such considerable size need not surprise us when we consider the enormous growth of the blepharoplast in the cycads (p. 389), or of the proximal centriole in the "middle-piece" of the urodele sperm (p. 379).

The Basal Apparatus of Ciliated Cells and the Henneguy-Lenhossék Theory. The basal bodies of the ciliated cell constitute an apparatus obviously similar in its general features to the basal apparatus of flagellated cells and involving the same questions. This apparatus, first carefully examined by Engelmann ('80) and Frenzel ('86) is as follows. At the base of each cilium, near the periphery of the cell, is a very distinct, intensely staining *basal body*, often clearly visible in the living cell, which has the same morphological relation to the cilium as the basal body of a flagellum and appears likewise to play the part of a blepharoplast in the formation of the cilium. From this body a delicate fibrilla extends outwards into the cilium as an axial filament, while inwardly it is prolonged into the cytosome to form the so-called ciliary root or basal filament, which is no doubt comparable to the rhizoplast of the flagellate. These filaments are often gathered together centrally to form a more or less conical bundle, extending downwards towards the nucleus and sometimes beyond it (Figs. 17, 18). The basal body is typically a minute rounded granule and in the simplest case is single (a common condition); but there are many complications of this simple type.[1] The basal body is often rod-shaped, sometimes dumb-bell-shaped, and in many cases is divided into a superficial or distal, and a central or proximal part; these are connected by the axial filament, often more or less thickened, which form the "basal rod" or "intermediate piece" of the cilium. In some cases the basal apparatus even consists of three basal bodies connected by the axial filament or basal rod. In addition to the foregoing, which belong to the basal apparatus proper, there is often a swelling of the free portion of cilium near its base, forming the so-called "ciliary bulb."

The analogy between the basal apparatus of ciliated cells and of flagellates or sperm-cells is so close as to raise the question whether here too the basal bodies may not be central bodies or their derivatives. That such

[1] *Cf.* Frenzel ('86), Böhming ('91), Heidenhain ('99), and references at p. 699.

is actually the case was urged by Henneguy ('97) and Lenhossék ('98), whose conclusions have since been generally known as the "Henneguy-Lenhossék theory." In columnar ciliated epithelium (epididymis of mammals) these observers found non-ciliated cells intermingled with the ciliated, closely similar to the latter in general type but containing a peripherally placed "diplosome" or pair of centrioles in place of the group of basal bodies characteristic of the ciliated cells. In the latter, diplosomes were not found; and the above-named observers could find no evidence of mitosis in the ciliated cell. They therefore concluded that the basal bodies represent a group of centrioles, probably derived by the multiplication of an original pair. Centrioles, blepharoplasts and basal bodies were thus regarded as homologous structures. This was supported by Meves' studies on the ciliated or multiflagellate oligopyrene sperms of *Paludina* (p. 300). Benda ('00) described the origin of basal bodies from centrioles in the ciliated cells of the ependyma and the epididymis of man; and similar results have been reached by several later observers, in particular Moreaux ('10, '12). Others likewise failed to find diplosomes in ciliated cells,[1] while many observers have been struck with the rarity of mitotic divisions in these cells, though it now seems to be established that such divisions may occur.

On the other hand, it seems now to have been conclusively proved that ciliated cells may contain a true microcentrum in the form of a pair of centrioles, situated in the outer region of the cell (as in epithelia generally) in addition to the peripheral group of ciliary basal bodies;[2] and some of these observers have produced evidence that the diplosome gives rise to the centrioles of the division-figure of such ciliated cells in mitosis, and that the basal bodies take no part in the process. The best evidence of this is offered by the work of Wallengren ('05) and Erhard ('10); but these observers differ as to the behavior of the ciliary apparatus, the former maintaining that both cilia and basal bodies disappear before mitosis, while Erhard asserts their persistence. These observers and others have considered these facts as decisive against the Henneguy-Lenhossék hypothesis, so far as ciliated tissue-cells are concerned; and another adverse argument has been based on the occurrence of basal bodies in the cilia of the ciliate Infusoria,[3] organisms in which mitosis seems to take place in the absence of either asters or clearly individualized central bodies. In spite of these apparent difficulties the writer shares the opinion of Prenant[4] that the last word had not yet been spoken on this subject. It seems entirely possible that in the ciliated cell,

[1] See Zimmerman ('98), Heidenhain ('99), Fuchs ('04), Joseph ('03), etc.
[2] Studnička ('99), Fischel ('00), Benda ('01), Gurwitsch ('01, '02), Wallengren ('05), Ikeda ('06) Tschassownikoff ('13).
[3] See Maier ('03), Mitrophanow ('03, '04), Hamburger ('03), Schuberg ('05).
[4] '12, p. 608.

as is so clearly seen in some of the flagellates, the basal bodies (blepharoplasts) though still retaining the power of multiplication by division, have wholly separated from the division-centers, so as no longer to take direct part in mitosis. Yocom ('18) has suggested that the blepharoplast of the flagellate is represented by the *motorium* of the hypotrichous ciliates, a body regarded as a probable center of coördination and connected by delicate fibrillæ with the bases of the anal cirrhi and the membranelles;[1] but there is no evidence to connect this structure with a division-center. The homologies between the basal apparatus of the ciliates and of flagellates thus remain in doubt.

II. CHROMIDIA, CHONDRIOSOMES AND GOLGI-BODIES

Both chromidia and mitochondria formerly belonged to that miscellaneous assemblage of granules known as "microsomes" (p. 32). Up to rather a late period the two were often confused, and even now considerable uncertainty exists concerning their identification. Theoretically an essential distinction lies in the fact that chromidia are of nuclear origin and are composed of "chromatin" while mitochondria are considered by nearly all recent students of the subject as strictly cytoplasmic; but in practice the determination of the origin of these bodies is not an easy task.

1. Chromidia

In the form of scattered or "distributed" nuclei chromidia were observed in various Protista (rhizopods, flagellates, bacterioid forms) by Gruber, Brandt,

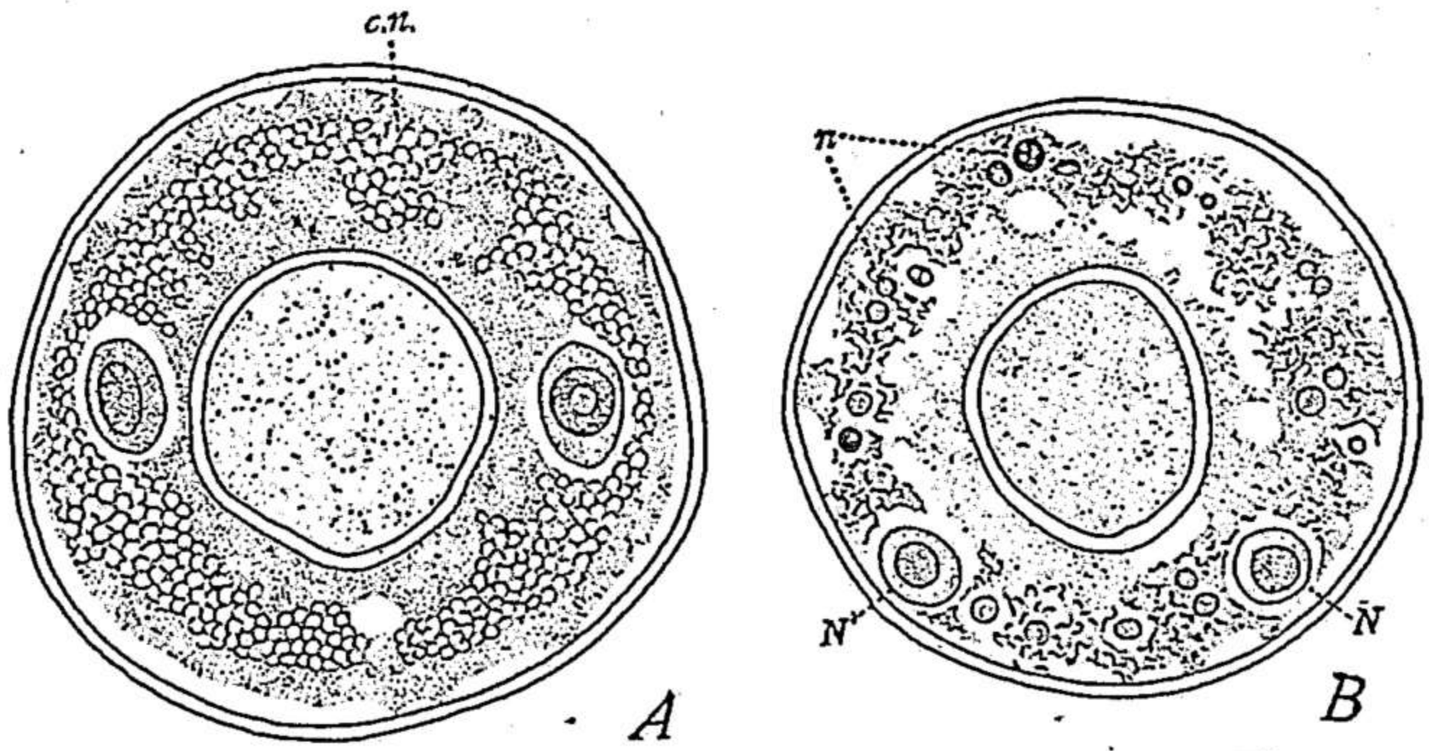

Fig. 342.—The rhizopod *Arcella*, showing nuclei and chromidia (R. HERTWIG). In each figure the large central circle represents the opening of the shell.
A, vegetative state with two nuclei and scattered chromidial net (*c. n.*); *B*, supposed secondary gamete-nuclei forming from chromidia (*cf.* Fig. 343).

Schewiakoff, Lister, Calkins and others some time before they attracted wider attention. Their theoretical interest was first fully recognized in the

[1] See also Taylor ('20).

so-called "chromidia hypothesis," founded by R. Hertwig and developed especially by Goldschmidt and others [1] who endeavored to extend it to the cells of vertebrates and gave to it a far-reaching theoretic elaboration. These later developments of the hypothesis, it must be said, have in considerable measure failed to meet the test of subsequent investigation. On its physiological side the most important development of the hypothesis has been the theory of nuclear dualism, which will be considered under a later heading (p. 725).

R. Hertwig first showed in certain heliozoan rhizopods, that the cytosome contains numerous intensely basophilic granules believed to be given off from the nucleus—hence his term "chromidia" (1902). In *Actinosphærium* during conditions of hunger or overfeeding the vesicular nuclei may break up completely into chromidia ("physiological degeneration"), the cell now being filled with chromidial granules, often forming a "chromidial net." If some of the nuclei remain intact the *Actinosphærium* cell is capable of complete recovery; if all the nuclei break down this seems to be impossible and the animal dies. In *Arcella* and other Thalamophora chromidia are given off in large quantities from the nuclei, without fragmentation, and give rise to a chromidial network; and Hertwig found that from this may be formed numerous small "secondary nuclei" (Fig. 342) which according to Schaudinn ('03), become the nuclei of minute gametes which conjugate in pairs.[2] More or less similar observations have since been made by a considerable number of observers, [3] who have found that in various Protista the nucleus may thus break down into chromidia, or give them off into the protoplasm by a process of emission; and that from such scattered chromidial formations new nuclei may reform. In some cases these nuclei are said to arise by the aggregation of chromidia, for instance, in the spore-formation of various bacteria; [4] in others by the enlargement (and multiplication?) of single chromidial granules. A good example of this is offered by the life-history of *Arachnula*, a primitive rhizopod originally described by Cienkowski ('76) as devoid of a nucleus and hence referable to Haeckel's "Monera." Dobell's recent studies of this form ('13) show that in its ordinary or vegetative condition it contains a variable number of vesicular nuclei. During encystment the nuclei are said to give off numerous chromidia to the cytoplasm and finally wholly to disappear as such, now being represented only by the scattered chromidial granules (Fig. 343).

[1] See especially R. Hertwig ('99, '00, '02, '04), Goldschmidt ('04, etc.), Goldschmidt and Popoff ('07), Popoff ('07), Schaudinn ('03, '07). For critique see Dobell ('09), Prenant ('10), Kofoid ('21).

[2] In the rhizopods *Polystomella*, *Centropyxis*, *Chlamydophrys* and *Entamœba*. The same was afterwards described by Elpatiewsky ('07) in *Arcella*, flagellates, gregarines, and other forms.

[3] Goldschmidt ('07), Schouteden ('07), Prowazek ('04, '05), Guilliermond ('07), Dobell ('13).

[4] See Schaudinn ('02, '03), Guilliermond ('08), Dobell ('08).

The cell thereupon breaks up to form a brood (10–20) of small daughter-cells, containing chromidia which give rise to a number of vesicular nuclei each of which seems to arise by the growth (and multiplication?) of a single granule.

If such accounts can be accepted it seems clear that the chromidial substance undergoes extensive growth, and that the number of granules largely increases in the course of the life-cycle. It is possible that this takes place by growth and division of the individual granules; and this view has been maintained by some observers, in particular by Schewiakoff ('93) who long since gave a careful description and figure of the

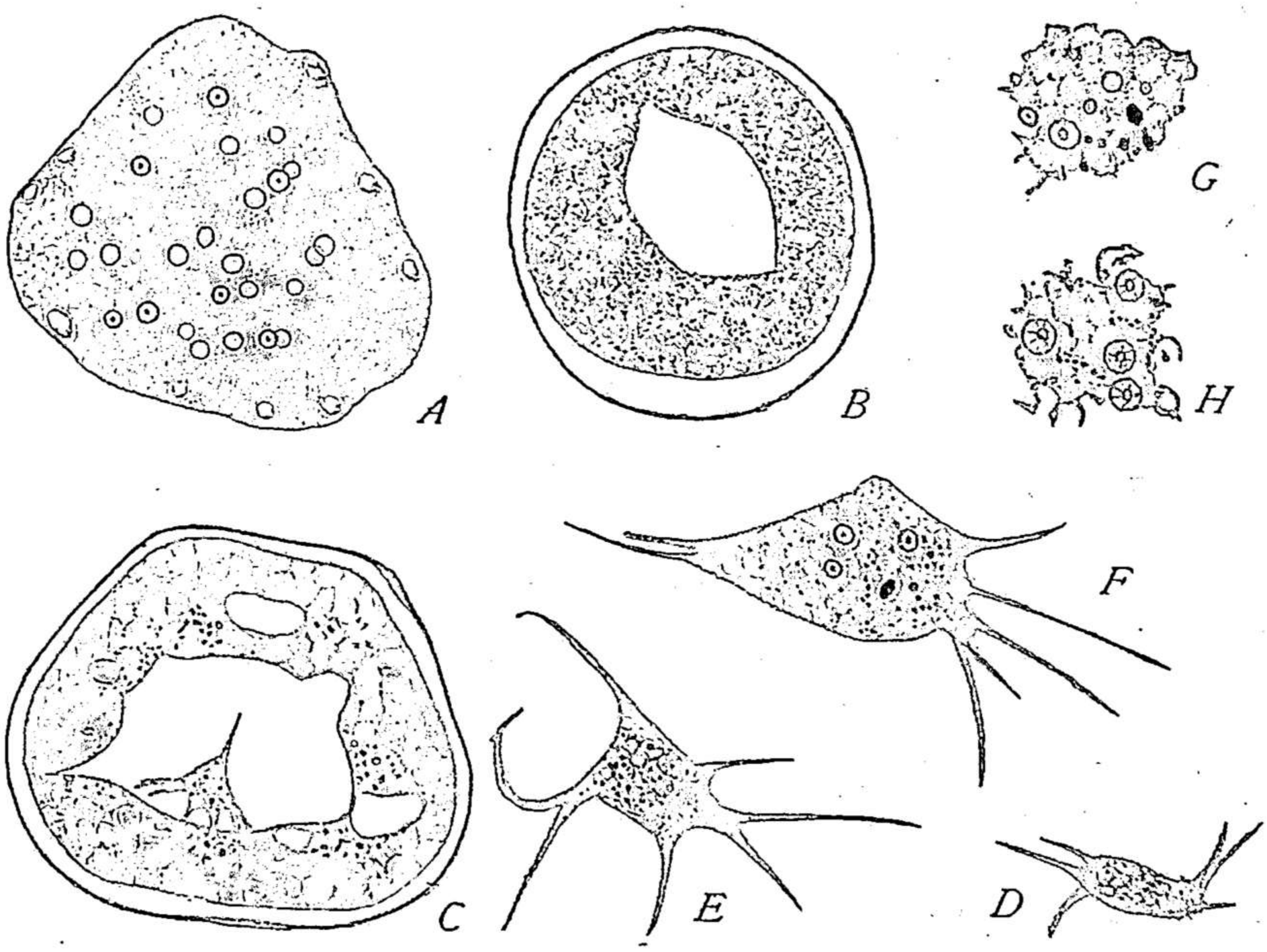

Fig. 343.—Chromidia and nuclei in the rhizopod *Arachnula* (DOBELL) (from fixed and stained specimens).

A, Individual ready for encystment, with many nuclei, no chromidia; *B*, encysted individual with large vacuole, nuclei broken down into scattered chromidia; *C*, endogeneous formation of daughter-cells; *D*, *E*, young chromidial daughter-cells, recently escaped; *F*, older form with nuclei forming, *G*, detail from individual similar to last, stages in formation of vesicular nuclei form chromidia; *H*, detail from mature specimen, nuclei and chromidia.

dividing chromidia in the large bacterium-like *Achromatium* (Fig. 32). This has never been sufficiently confirmed by later observers, either in bacteria or other Protista; nevertheless, there has been a rather general, more or less tacit, assumption that the chromidia are endowed with such powers.

The chromidia hypothesis underwent a sudden expansion with the works especially of Goldschmidt, Popoff and still later of Buchner and of Schaxel

by whom an attempt was made to extend it to the Metazoa and to elaborate a general theory of the chromidia. Goldschmidt ('04) described in the epithelial, muscular, glandular and connective-tissue-cells a "chromidial apparatus" consisting of basophilic granules and fibrillar formations which were assumed, mainly because of a general similarity of staining-reactions, to be extruded basichromatin destined to play a particular rôle in the trophic functions of the cell (p. 726); and Goldschmidt accepted the probability of a similar origin of many other well-known cytoplasmic structures, including the mitochondria, the yolk-nucleus, nebenkern, pseudochromosomes, reticular apparatus, ergastoplasm and cytomicrosomes. These conclusions were extended to the germ-cells by Wassilieff ('07), Popoff ('07), and Buchner ('09, '10), all of whom concluded that the cytoplasmic granules and filaments aggregated near one pole of the nucleus, of the auxocytes, in the early growth-period (p. 330), are chromidia extruded from the nucleus, at or near the time of the synaptic or "bouquet" stage of maturation (p. 543). An actual extrusion of chromatin from the free ends of the threads at this time was in fact described by Buchner ('09, '10) and Jörgensen ('10); but these results have either been contradicted or have failed of sufficient support by later observers. The nuclear origin of Goldschmidt's "chromidial system" in nematodes was specifically denied by later workers,[1] and it was made clear that many of the other elements of the so-called "chromidial system" in Metazoa are of mitochondrial and not of nuclear origin. In case of the germ-cells it was clearly demonstrated by Duesberg ('11), Fauré-Fremiet ('10), Van der Stricht ('05, '11, etc.) and others, that the granules and fibrillæ aggregated at the nuclear pole in the bouquet stage are typical cytoplasmic chondriosomes, already present before the polarization of the spireme-threads and derived from chondriosomes of the spermatogonia.

Widespread scepticism thus arose concerning the whole conception of chromidia as applied to the Metazoa. Some observers still hold to the view that chromidia and mitochondria coexist in the cell as independent though often closely similar structures. Schaxel [2] in particular has devoted an interesting series of papers to the general thesis that differentiation or cytomorphosis is largely brought about by a periodic emission of chromatin from the nucleus, beginning already in the unfertilized egg and continuing during cleavage and development. Schaxel's figures of the supposed chromatin-emission are among the most careful in the literature (Fig. 344). If they do not seem to the writer conclusive it is because of the extreme difficulty of arriving at a certain conclusion from the study of sections

[1] See Vejdovský ('07), Bilek ('09. '10), Hirschler ('12) and especially Kemnitz ('12).
[2] See especially ('10, '11, '12, '13, '15).

alone.[1] On the other hand, it is important not to lose sight of the fact, which has been emphasized by many observers,[2] that at every mitosis residual nuclear material is set free into the cytoplasm; and in case of the germinal vesicle of the ovum this material, very large in amount, may play

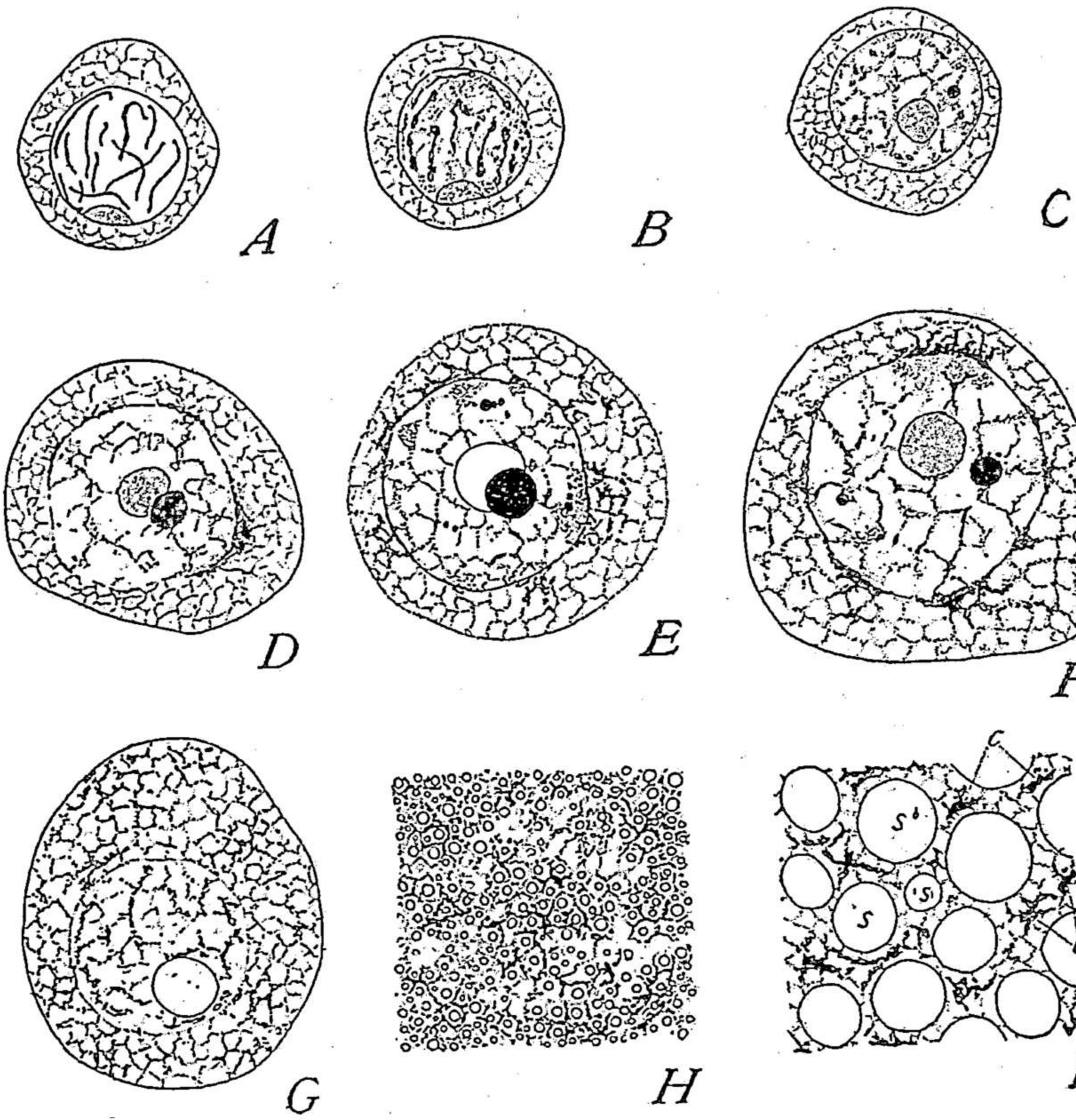

Fig. 344.—Supposed chromidia-formation in the animal egg (SCHAXEL); (*A–F*, in the annelid *Aricia; G* in *Holothuria; H*, *I*, in the medusa *Pelagia*).

A, *B*, early oöcytes; *C*, reticular stage; *D-F*, stages of "chromatin-emission"; *G*, cytoplasmic "chromasia" following emission; *H*, cytoplasmic detail in later oöcyte, small yolk-spheres appearing with chromidial granules scattered between them; *I*, from mature egg, with yolk-spheres (*s. s.*) and inter-vitelline chromatin-remnants (*c*).

a direct and important part in building the body of the embryo.[3] F. R. Lillie ('06) showed that in the annelid *Chætopterus*, the nuclear granules (microsomes) of this substance are visible in the living eggs; that upon their liberation, as the wall of the germinal vesicle breaks down, their staining-reaction changes from acidic to basic (with thionin and orange); that they

[1] Beckwith ('14) who has carefully reëxamined the phenomena in the oöcytes of hydromedusæ was unable to confirm Schaxel's account. See also the work of Dantschakoff ('16), and of Van Herwerden ('13).

[2] See Wilson ('95, etc.), Conklin ('02, etc.).

[3] See especially Conklin ('05) and Lillie ('06).

can still be distinguished as basic-staining "microsomes" during early cleavage and undergo a fairly definite distribution to the embryonic cells. Lillie also observed the liberation of another and larger type of granules at each cleavage-mitosis, in addition to the setting free of oxychromatin, emphasized by earlier writers.

The facts, apparently, are here well determined, and there seems to be no valid reason why the granules thus derived from the nucleus should not be called "chromidia." The possibility is here opened that such bodies, once set free, may long retain the powers of growth and division, and be capable of definite chemical transformations, and that they may even give rise to bodies indistinguishable from mitocondria which, unless their whole history be followed out, would appear to be of strictly cytoplasmic origin.

Further interesting possibilities are offered by the recent work of K. E. Schreiner who has produced evidence that certain types of secretory granules arise by the extrusion from the nucleus of fragments of the true nucleolus. In a first paper ('15) this conclusion is reached in case of the subcutaneous fat-producing gland-cells of the epidermis in *Myxine;* in later works ('16, '18) it is extended to the remarkable slime-producing gland-cells of the epidermis. These cells contain numerous intensely fuchsinophilous granules and fibrillæ, called by Schreiner *plasmosomes* (following Arnold and Held), and are identified by him with Altmann's plasma-elements (granules and their products). Schreiner believes that, in some cases at least (the small mucus-producing cells) the plasmosomes are capable of independent growth and division, and that they may thus be handed on from cell to cell in mitosis. The filaments may arise from the granular forms either by elongation or by linear alignment, and conversely the filaments may break up into granules, a process that always precedes mitosis. By the transformation of these bodies are said to arise both the fat-drops or lipoid granules and the long, spiral threads of mucus-producing material in which form the secretion is discharged from the cell; and Schreiner further concludes that in the sensory cells the neurofibrils may arise by direct transformation of the "Altmann threads."

All this is in harmony with the results of Altmann himself (pp. 74–77) and of those who have ascribed a similar physiological rôle to the chondriosomes (Benda, Meves), as described beyond (p. 708). The point which especially interests us here is Schreiner's conclusion that the Altmann elements (granules and fibrillæ) originally arise *by extrusion of fragments of the true nucleoli*, either in the basal cells or in their products.[1] Could this result be accepted it would go far towards a reconciliation of the chromidia hypothesis and that of the chondriosomes. The conclusions of so experience-

[1] See also p. 345 for an account of the formation of yolk-spheres from nucleolar fragments.

and competent an observer carry great weight; neverthless it must be said that they still await more convincing evidence than has yet been produced.

2. The Chondriosomes

Most of the bodies now called chondriosomes were described by the earlier cytologists under other names (p. 46); and even the theoretical aspects of the "chondriosome-theory" were in most essentials worked out by Altmann and others some time before the more modern development of the subject. This development was due, first to technical improvements by Benda ('97–'01) and his successors, which made it possible to fix and stain the chondriosomes with greater certainty and brilliancy; and secondly, to a theoretical treatment by Benda and Meves nearly akin to Altmann's but avoiding many of the errors into which that writer had fallen. With these authors arose a new terminology, which, as has so often happened before, contributed to the impression that the chondriosomes represented a newly discovered cell-component. But, as most of the leading investigators in this field have clearly recognized, what was new was not the thing itself or even its theoretical treatment but only an impulse to its further investigation. Due in the first instance to Benda, this was carried forward especially by Meves and Duesberg, and more recently by Regaud, Fauré-Fremiet, Guilliermond, Bensley, Cowdry, the Lewises and many others.

The most salient histological characters of the chondriosomes have earlier been indicated (pp. 45–47). In their broader bearings they are of general interest in relation to the phenomena of histogenesis and considered as possible factors in differentiation and heredity.

a. Chondriosomes and Histogenesis. As applied to the phenomena of histogenesis the chondriosome-theory is essentially a modernized development of Altmann's granule-theory (p. 74). It began with the identification of mitochondria in the germ-cells, and was followed by Benda's demonstration of their presence in both egg and sperm and in the blastomeres of the sementing egg (*Triton*), and of the fact that they are handed on from cell to cell without loss of their identity during the processes of mitosis (p. 163). These facts, repeatedly confirmed by more extended observation in later years, led Benda to suggest that mitochondria introduced into the egg by the sperm may take part in the process of fertilization; further that they may be handed on by division to the embryonic cells; that from them during histogenesis may arise more specialized structures, such as the myofibrils, the basal bodies of the cilia, etc.; and finally, that the mitochondria must be regarded as definite and permanent cell-organs, identical in part with the "microsomes" of earlier writers and the "bioblasts" of Altmann,

which play a definite part in heredity.[1] Benda thus offered, in brief outline a general far-reaching hypothesis of the chondriosomes, about which quickly gathered numerous more detailed studies supporting his main conclusions.

The lead in this movement was taken by Meves, who has contributed many interesting works in support of Benda's general conclusions; but an important part in it was played by Duesberg, Regaud, Hoven, Fauré-Fremiet, Guilliermond and many others. The demonstration, it must be confessed, still leaves much to be desired and a considerable group of excellent observers, *e. g.*, Retzius, Vejdovský, Cowdry and Mottier, have taken a sceptical attitude towards the whole hypothesis. In some directions, clearly, the chondriosome-theory has far outrun the facts; in others it has met with direct contradiction by observation. But if it is not yet fully ripe for discussion it has too many facts in its favor to be lightly dismissed.[2]

Meves ('08) found numerous chondriosomes, in the form of mitochondria and chondrioconts, in all kinds of embryonic cells (in vertebrates) up to a stage when histogenesis is well advanced, and pointed out that these bodies are in all probability identical with Altmann's granules and fibrillæ; further, that the chondrioconts represent the *fila*, or separate fibrillæ of Flemming ('82). By the transformation of these embryonic chondriosomes, in the view of Meves, arise various other formed bodies, including the myofibrils of both smooth and striated muscles, the neuro-fibrils, the fibrillæ of the neuroglia- and connective-tissue-cells, the basal filaments of ciliated cells, the fibrillæ of glandular epithelia and many forms of granules, including the secretory, the pigment-granules, and the yolk-spheres. A long series of later works were devoted by Meves to the support and extension of these conclusions, including the proof that during fertilization the sperm brings into the egg mitochondria which mingle with those of the egg (p. 435) thus providing a biparental store of these bodies to be drawn upon during development as material for histogenesis of the formed components of the tissues.

The foregoing conclusions have formed the subject of numerous special investigations since 1908 without having led as yet to any general agreement among cytologists. There are few of the cytoplasmic formed bodies that have not been supposed to be products of chondriosomes; but few of these conclusions have not been contradicted by other observers. For example, both Benda and Meves believed the myofibrils to arise by direct transformation of the embryonic chondrioconts (Fig. 345). This was supported by the

[1] Benda, '03, pp. 749, 781.

[2] General reviews of the literature are offered by Benda ('03), Meves ('08), Prenant ('10), Duesberg ('12, '20), the Lewises ('15), Guilliermond ('14, '19, etc.), Schreiner ('16), Meves ('18), Cowdry ('18, '24) and Nassonov ('23).

accurate and detailed studies of Duesberg ('09, '10), later by those of Leplat ('12), Luna ('13), Brück ('14), Torraca ('14) and others, and has been adopted by a number of leading histologists, including Prenant ('11) and Schäfer ('12). On the other hand, this conclusion is sceptically regarded by Heidenhain ('11), Gurwitsch ('13) and Cowdry ('19), who have pointed out various difficulties and sources of possible misinterpretation. The case is similar with the neurofibrils and other fibrillar formations. Hoven ('10), for example, brought forward detailed evidence that the neurofibrils are derived from embryonic chondrioconts, but this too has been strongly opposed, particularly by Cowdry, who has devoted particular attention to the problem ('12, '14, etc.).

Interesting possibilities in this direction are offered by the relation of the chondriosomes to secretion and related chemical processes in the cell, and to the formation of plastids. Altmann, Arnold, and other advocates of the granule-theory believed that the secretory granules or "zymogen-granules"

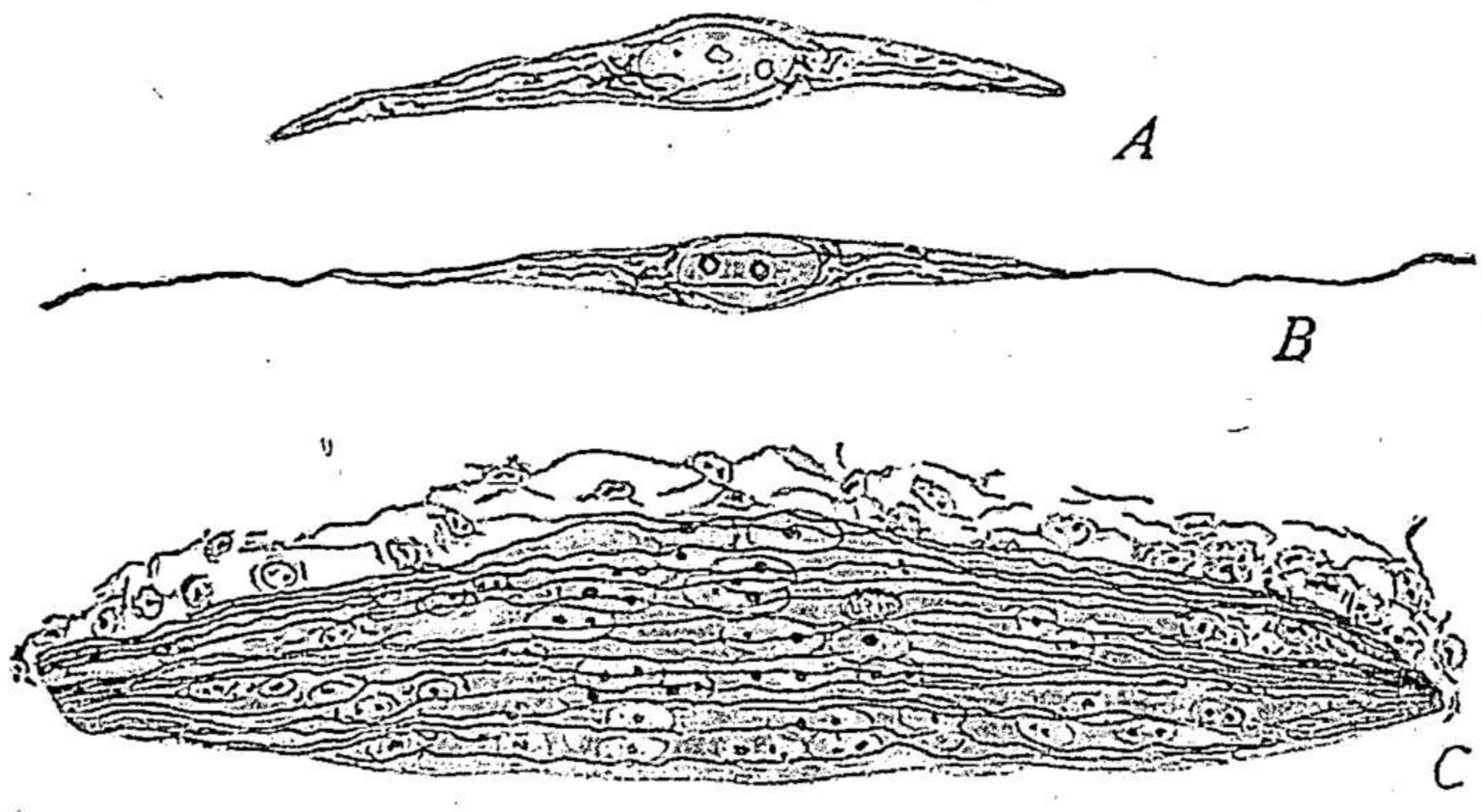

Fig. 345.—Supposed transformation of chondriosomes into myofibrils, from embryo chick (DUESBERG).

A, myoblast, about 60 hours, with chondrioconts; *B*, myoblast of 76 hours; *C*, frontal section of myotome; 96 hours, with developing myofibrils.

are not formed *de novo*, as earlier observers had supposed, but arise from preëxisting protoplasmic granules ("bioblasts" or "plasmosomes"); and this conclusion has been accepted by many competent histologists (*e. g.*, M. Heidenhain, '11) some of whom likewise believe them to be products of the chondriosomes.[1] This conclusion appears in a somewhat different light in view of Nassonov's recent conclusions concerning the possible relation of the Golgi-apparatus to secretion, to be considered in the following section. Here we only emphasize the fact that not only the secretory granules proper but many other specific types of granules have by many observers

[1] See Regaud ('09), Hoven ('10, '11), Grynfelt ('12, '13), Laguesse ('11), Dubreuil ('13), Saguchi ('20), etc.

been assumed to arise from chondriosomes. Among these may be mentioned granules of fat (see especially Dubreuil '11, '13); yolk-granules (Fig. 348) (Van der Stricht, Loyez, Russo, Fauré-Fremiet, Hirschler); pigment of various types (Arnold, Meves, Ciaccio); the granules of leucocytes (Meves) and of connective-tissue-cells (Prenant, Dubreuil). Some of these observers believe the granules to arise by the direct morphological transformation of original mitochondria or chondrioconts; others, that they are secondary products of mitochondrial activity. In either case the chondriosome is regarded as a *localized center of specific chemical transformation*, a view urged especially by Regaud ('09, '11), who compared the chondriosomes in this respect to the plastids of plant-cells, which undoubtedly are such centers of action. Physiologically, in Regaud's view, the chondriosomes are "electosomes" which have a specific selective action upon the surrounding cytoplasm and are centers of specific chemical elaboration and accumulation.

Support is brought to this conception by the conclusion that *plastids themselves are enlarged and transformed chondriosomes*. This conclusion, first reached by Levitsky and Pensa, was later supported particularly by Guilliermond and others and still more recently by Meves and by others [1] who have described, in a very detailed manner and in a considerable variety of objects, the transformation of the chondriosomes into plastids in the embryonic tissues and their products. That the plastids in these tissues are often very small and numerous has long been familiar (p. 43). Levitsky, Guilliermond, Meves and Twiss show that in their earliest stages they are indistinguishable from chondriosomes (Fig. 19) and that all intermediate stages may be traced between them as histogenesis proceeds. Most commonly the chondriosomes have originally the form of chondrioconts (rods or threads), but in some cases they are granules or mitochondria, as described for instance by Guilliermond in the parenchyma where they give rise to amyloplasts (Fig. 346). As the cells grow older these chondriosomes are gradually transformed into plastids, producing chlorophyll in case of the chloroplasts, anthocyanin in that of the chromoplasts, starch in the amyloplasts, or fat in case of the elaioplasts. Guilliermond's observations seem to afford strong evidence that some of these substances (in particular starch) are originally laid down as solid deposits within the chondriosomes, others (pigments) are dissolved in their substance. In either case the chondriosome enlarges in later stages to form the body of the plastid, meanwhile undergoing various changes of form. During this process the power of division may be retained (as in case of the chloroplasts) or finally lost (apparently in case of the amyloplasts).

[1] Levitsky ('10, '11), Pensa ('10, '14), Guilliermond ('12, '13, '14, '17, '20), Forenbacher ('11), Maximow ('13), Cavers ('14), Meves ('17), Twiss ('19), Nassonov ('20), Ernberger ('20).

These results seem to give substantial ground for accepting the derivation of plastids from chondriosomes, and indirectly lend greater probability to the hypothesis that the latter may have the powers of independent growth and division, at least in some stage of their history. On the other hand, the foregoing conclusions concerning the origin of the plastids have been contested, in particular by Rudolph ('12), Sapĕhin ('13, '15) and Mottier

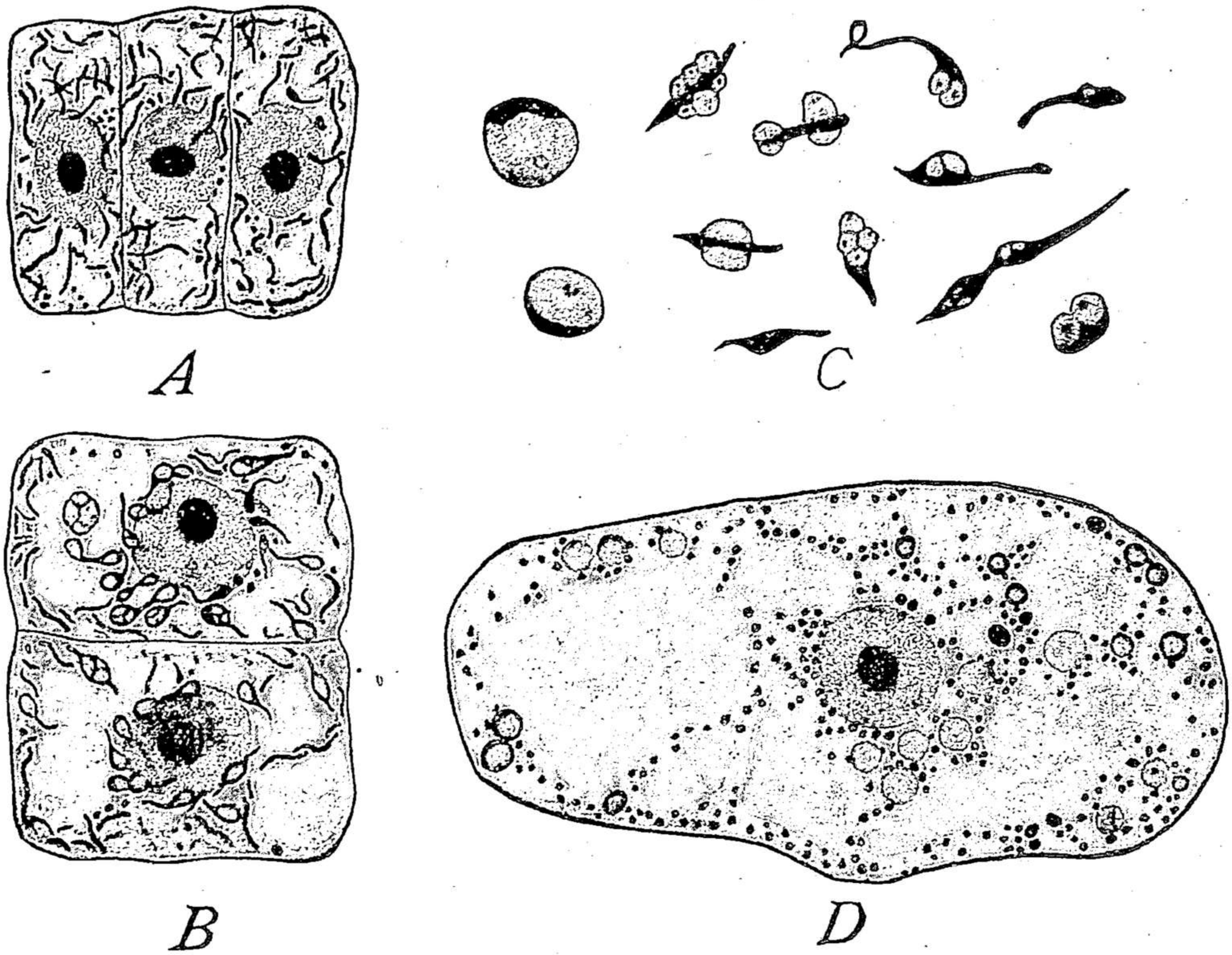

Fig. 346.—Chondriosomes and plastids in plant cells (GUILLIERMOND).

A, cells from growing root-tips of barley, with chondriosomes; *B*, older cells from same, starch-grains forming inside the chondriosomes (now amyloplasts); *C*, more enlarged amyloplasts; *D*, cell from potato-tuber, mitochondria (small granules), leucoplasts, and starch-granules.

('18), who hold that the embryonic plastids are from the first distinct from the chondriosomes, just as has been maintained in case of the myofibrils, neuro-fibrils and secretory granules. It is not disputed, however, that in the embryonic tissues the smallest plastids are hardly if at all distinguishable from chondriosomes.

The evident difficulty of settling this question by direct observation has led to many attempts to approach it indirectly by study of the relative number of chondriosomes at successive periods of histogenesis; for, if the embryonic chondriosomes are converted into differentiated elements of the

tissue-cells, their number should progressively diminish as histogenesis proceeds. Such a diminution was in fact observed by Meves ('08) during histogenesis in chick-embryos and now seems to be well established, both for plants and animals, and also by the fact that in old and senescent cells the mitochondria may nearly or quite disappear. In the salivary glands, for instance, Regaud and Mawas ('09) found the number of mitochondria to be inversely proportional to that of secretory granules; the number of the former progressively decreasing as that of the latter increases. A similar relation was found by Guilliermond ('12) in respect to chondriosomes and plastids in embryonic plant-cells. This question has been carefully examined in the development of animals especially in *Ascaris* by Held ('12) and Romeis ('13) and in mammals by Rubaschkin ('10) and Levi ('15). All these observers have found, though with some variations, that the number of chondriosomes ultimately diminishes as development proceeds, though in *Ascaris*, Romeis described a progressive multiplication of mitochondria during the cleavage stages. In the bat, on the other hand, Levi's detailed studies clearly show that the mitochondria, very small and numerous in the fertilized egg, steadily become less numerous during cleavage, since at each division their number is halved. As this process advances they increase in size and are gradually transformed into the chondrioconts with which the embryonic cells are filled and which are said to form the source of the various intra-cellular differentiations. Beyond this point no further diminution occurs—a fact supposed to be due to a resumption of the power of division by the chondriosomes. It thus comes to pass that undifferentiated chondriosomes may still persist, in greater or less degree in the most highly differentiated cells, such as nerve-cells (Cowdry), striated muscle-cells (Benda, Regaud) or in the chloroplast-containing cells of plants.

Convincing as some of these observations seem it must be recognized that the subject is still in too confused a state to warrant any very definite conclusions concerning the rôle of the chondriosomes in histogenesis. Researches in this field have nevertheless opened many interesting possibilities which to say the least should not be rejected until they have been far more thoroughly examined. In particular the supposed origin of plastids from chondriosomes deserves the most critical further examination; for should it finally be established it would tell strongly in favor of the general chondriosome-hypothesis as developed by Benda, Meves and their followers and also of the general conception of protoplasmic organization advocated by Altmann, Arnold and other adherents of the granule-theory.

b. Growth and Division of the Chondriosomes. The chondriosomes undoubtedly possess remarkable powers of growth, as is seen for example in the auxocytes of many animals (p. 364). Whether such growth is followed or

accompanied by division—as is the case, for example, with plastids or chromosomes—is, however, by no means clear; and the question is complicated also by the fact that smaller chondriosomes may fuse or closely unite to form larger ones until the whole chondrioma may be condensed into a single massive body (pp. 364, 371).

As earlier indicated, the behavior of the chondriosomes during mitosis (chondriokinesis), as seen particularly in the spermatocytes, is of two apparently widely different types (p. 163) in one of which these bodies become distinctly aggregated about the spindle,[1] while in the other they remain scattered through the cytosome. In the first of these cases it seems certain that some of them, at least, are cut through transversely during mitosis; though this may be a merely passive or mechanical result of cytokinesis. In the second case it seems equally certain that many if not all of them pass undivided towards the poles (p. 163). When (as in *Centrurus*, p. 364) all the chondriosomes unite into a single dividing body, there is no evidence that its components undergo division during mitosis; the reverse conclusion seems more likely. Such cases make it certain that the actual distribution of chondriosome-material is not necessarily effected by a process of fission at the time of mitosis; but neither do they exclude the possibility that the chondriosomes may have arisen by division at an earlier period.

In the protozoa a number of observers (Künstler, Wallengren, Prowazek and others) have observed granules, spherules, or rods in the form of dumb-bells and have interpreted them as forms of division. Fauré-Fremiet (1907–08) followed, in the living object, the actual division of such bodies synchronously with that of the nucleus, and showed that in sections they are not to be distinguished in their staining reactions, or otherwise, from the chondriosomes of higher forms (Fig. 346*a*). Here also they show all stages of constriction, dumb-bell and diplococcoid forms.[2] On the whole, nevertheless, the direct evidence of division on the part of the mitochondria still remains very deficient; and to this extent the whole theory is insecurely based. Its strongest support is offered by the history of the plastids; but even here, it must be admitted, the case is far from closed.[3]

There is still no satisfactory evidence that the chondriosomes play any part in fertilization. Not the slightest proof has been produced of a fusion between the paternal and maternal chondriosomes. It is not even certain that those brought into the egg by the sperm do not degenerate as main-

[1] See Meves ('00, '03, '07, etc.), Benda ('03), Meves and Duesberg ('08), Giglio-Tos and Granata ('08), Duesberg ('10, '11), Fauré-Fremiet ('10), Terni ('11), Levi ('13), Lewis and Robertson ('16), Bowen ('20), etc.

[2] See Rubaschkin ('10), Romeis ('13), Meves ('16, '17).

[3] Wallin ('22, a, b, c) has emphasized the close similiarity, both in structure and in staining-reaction, between chondriosomes and bacteria, and has even suggested that they may actually be bacterial symbionts. For criticism see Cowdry ('23), Bowen ('23).

tained by Vejdovský ('11) and Retzius ('11); and this is admitted even by Meves himself ('13, p. 235). On the other hand, Held ('18) believes that by the use of molybdate hæmatoxylin and acid fuchsin the less dense paternal mitochondria may be stained red while the maternal ones remain deep black, and that it may thus be shown that the sperm-mitochondria grow

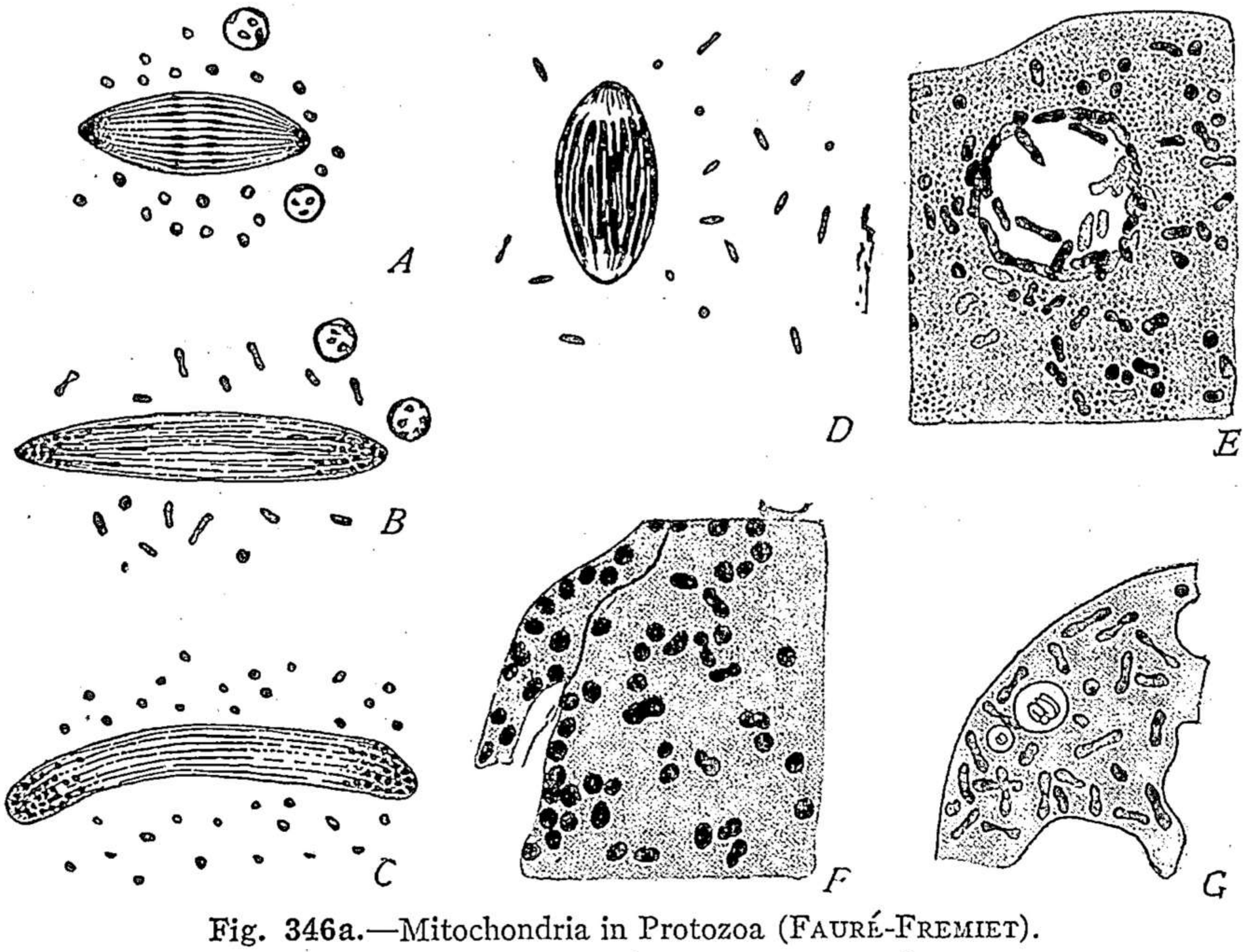

Fig. 346a.—Mitochondria in Protozoa (FAURÉ-FREMIET).

A–C, three successive stages, observed *in vivo*, showing supposed division of the mitochondria synchronously with the micronucleus; *D*, the same in *Urostyla*, from a fixed preparation; *E*, division-stages of the mitochondria surrounding the contractile vacuole in *Carchesium* (fixed preparation); *F*, mitochondria from *Opisthonecta; G*, dividing mitochondria, *Campanella*.

and rapidly multiply by division without the occurrence of a process of fusion during fertilization or up to the first cleavage.

Without entering upon all the doubtful questions here involved we only emphasize once more the fact, determined by Meves himself, as well as by others, that in some animals the mitochondrial formations derived from the sperm do not enter all of the cells of the embryo. In the sea-urchin, Meves found ('11, '12, '14) that the mitochondria-containing middle-piece remains intact and almost unmodified during the first five cleavages, being found in only one blastomere up at least to the 32-cell stage. In order to save his hypothesis Meves was therefore driven to the improbable assumption that the adult sea-urchin is formed only from cells which receive the spermatic chondriosomes, while those which fail to receive them are concerned only with the formation of larval structures which sooner or later degenerate in the course of the ontogeny.[1]

[1] See Meves (18)

3. The Golgi-Apparatus

Too little is known of the Golgi-apparatus, morphologically and physiologically, to warrant extended discussion at this time. Whether the Golgi-bodies have a persistent identity and multiply by growth and division is unknown; but their history in cell-division (p. 165) leads us at least to

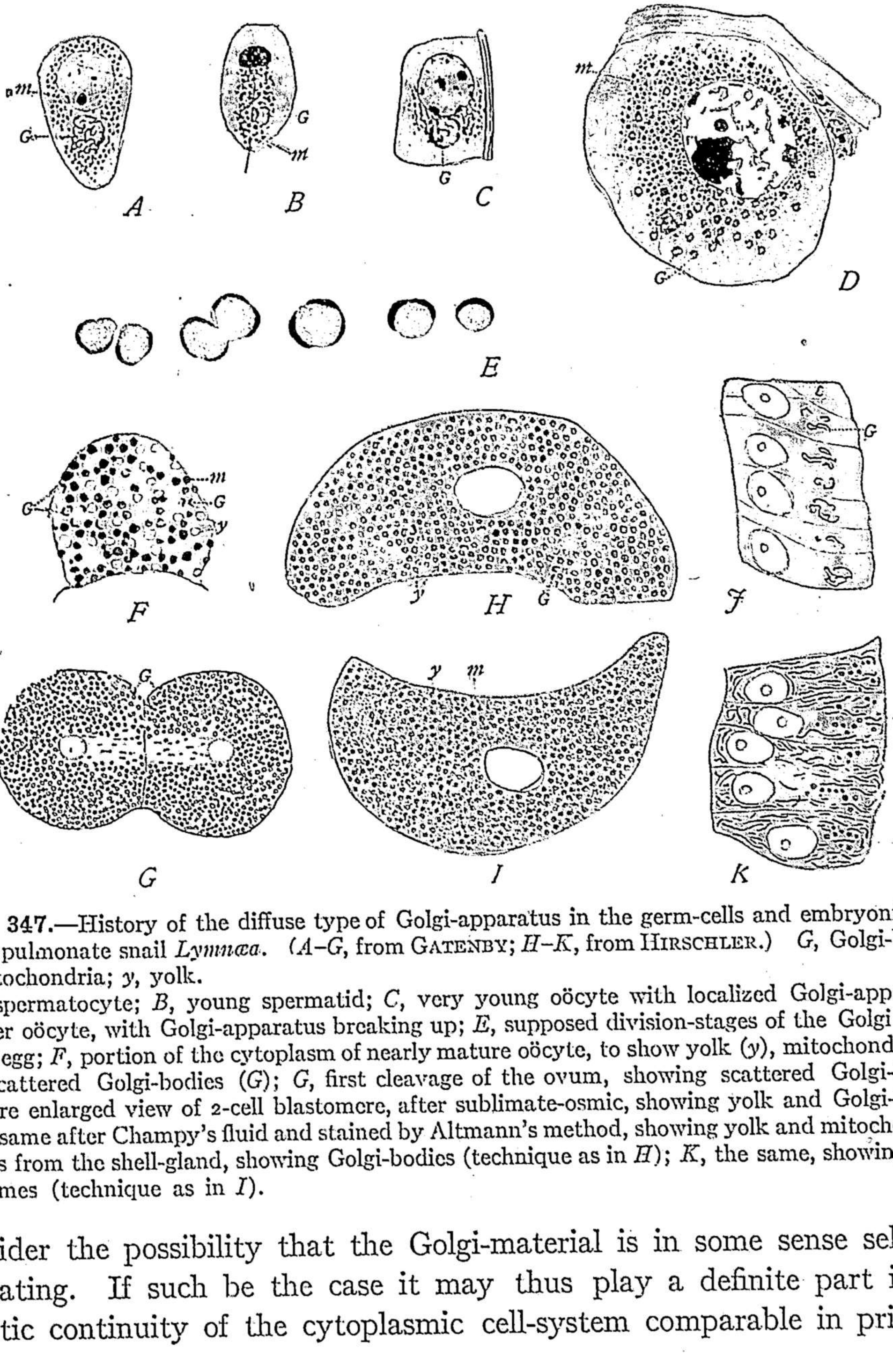

Fig. 347.—History of the diffuse type of Golgi-apparatus in the germ-cells and embryonic cells of the pulmonate snail *Lymnæa*. (*A*–*G*, from GATENBY; *H*–*K*, from HIRSCHLER.) *G*, Golgi-bodies; *m*, mitochondria; *y*, yolk.

A, spermatocyte; *B*, young spermatid; *C*, very young oöcyte with localized Golgi-apparatus; *D*, later oöcyte, with Golgi-apparatus breaking up; *E*, supposed division-stages of the Golgi bodies in the egg; *F*, portion of the cytoplasm of nearly mature oöcyte, to show yolk (*y*), mitochondria (*m*) and scattered Golgi-bodies (*G*); *G*, first cleavage of the ovum, showing scattered Golgi-bodies; *H*, more enlarged view of 2-cell blastomere, after sublimate-osmic, showing yolk and Golgi-bodies; *I*, the same after Champy's fluid and stained by Altmann's method, showing yolk and mitochondria; *J*, cells from the shell-gland, showing Golgi-bodies (technique as in *H*); *K*, the same, showing chondriosomes (technique as in *I*).

consider the possibility that the Golgi-material is in some sense self-perpetuating. If such be the case it may thus play a definite part in the genetic continuity of the cytoplasmic cell-system comparable in principle

to that shown by the chondriosomes, the plastids or even the central bodies, The all but universal presence of this material in all types of animal cells, and the remarkable uniformity of behavior which on the whole it displays, point to its fundamental importance in the activities of cells generally. Its possible relation to the secretory processes, suspected by various earlier observers,[1] has been emphasized by the recent work of Nassonov, who

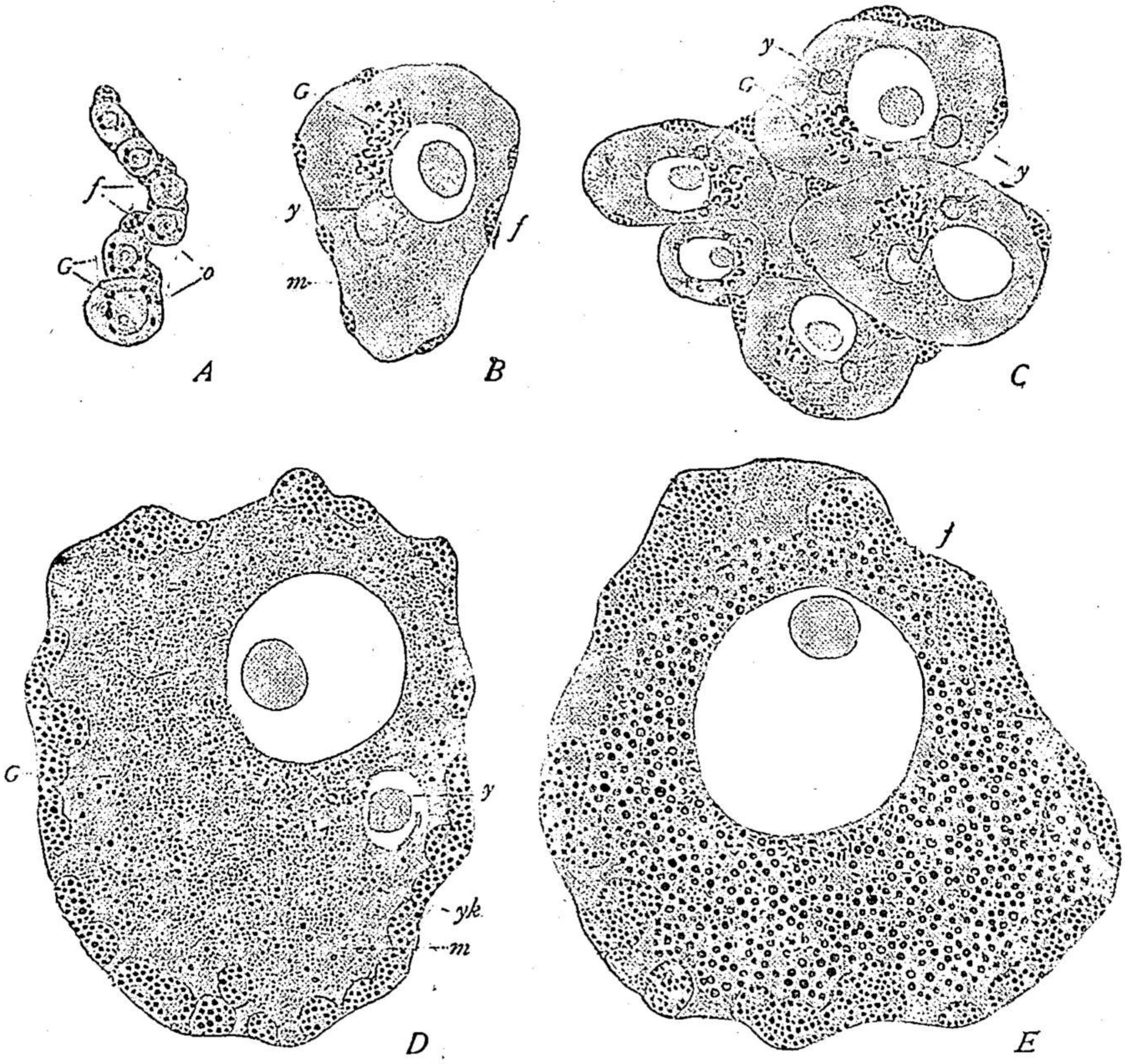

Fig. 348.—Yolk-nucleus, Golgi-bodies, mitochondria and yolk in oöcytes of the tunicate *Ascidia* (HIRSCHLER).

A, very young oöcytes, (*o*) with follicle-cells (*f*) and scattered Golgi-bodies (*G*); *B*, *C*, older oöcytes, showing yolk-nuclei (*y*); scattering of the Golgi-bodies and mitochondria (*m*); *D*, *E*, still older stages, with diffuse Golgi-bodies, mitochondria and yolk-spheres, the latter (pale) more peripheral in position.

has closely studied the question in the pancreas, epididymis and other glands by the use of new and improved methods. This work seems clearly to show that the secretory granules first make their appearance in close relation to the Golgi-apparatus in close contact with or actually imbedded in its meshes, and are subsequently set free into the general cytoplasm where

[1] *E. g.*, Fuchs ('02), Biondi ('11), Golgi ('09), Zawarzin ('09), Cajal ('14), Deineka ('16), Cowdry ('22). Lit. in Nassonov ('23).

they enlarge to form the definitive zymogen granules, while the Golgi-apparatus resumes its compact appearance.[1] Nassonov does not deny that the chondriosomes may play some part in the process, perhaps as an intermediary between the dissolved materials of the secretion and the actual secretory granules formed by the activity of the Golgi-bodies. "The zymogen-granules first appear in the form of minute bodies inclosed in the osmophilic substance of the Golgi-network. The meshes of the network thus appear as the matrix of the secretion in the cell. . . . After attaining a certain size the granules separate from the network and lie free in the cytoplasm . . . until they dissolve and pass as a liquid secretion into the lumen" (*op. cit.*, p. 431). Bowen ('23) has confirmed the most essential features of Nassonov's account; and we may also recall here the evidence produced by Hirschler and by Gatenby (p. 345) that the Golgi-bodies may be directly concerned in the production of the yolk-spheres (Fig. 347). In view of all this it is hardly to be doubted that the Golgi-apparatus plays an important part in secretion and related processes; but the presence of this structure in non-glandular cells such as nerve-cells, muscle-cells, connective-tissue-cells, and above all in the sperm-cells (p. 361), indicates that it possesses a much broader significance. Bowen has pointed out the close analogy between the formation of the acrosome in the animal sperm and that of a secretory granule, and has suggested that in both cases the Golgi-apparatus may be a center for the formation of enzymes which in case of the acrosome may play a part in the activation of the egg (p. 435). This at least suggests a new angle from which the puzzle of the Golgi-apparatus may be viewed.

4. Summary and Critique

In their fundamental aspects, evidently, the problems presented by the chondriosomes and Golgi-bodies are still in a somewhat confused state; and the same may be said of the cytoplasmic granules generally. The evidence is still too conflicting to allow us to draw a sufficiently clear line between the objective and the theoretical sides of the subject; and in this respect students of the cytoplasmic structures are at a disadvantage as compared with those of the nucleus because of the almost total lack of genetic evidence. Modern genetic experiment has given an overwhelming demonstration not only of the leading rôle played by the nucleus in heredity but also of its particulate or corpuscular organization, in the sense that it is composed fundamentally of small entities ("genes," "factors," or the like), that are self-perpetuating and within certain limits independent

[1] In these glands, as is the rule, the Golgi-complex lies always between the nucleus and the lumen of the gland. In the thyroid Cowdry ('22) found it often also in the basal region, a fact which he correlates with the supposed secretion of these cells either into the lumen or into the blood.

of one another. We have very little such genetic evidence in case of the cytosome; but the fact that it is available in case of the nucleus predisposes us to adopt a similar conception of the cytoplasm. We are likewise predisposed in favor of the theory of chromidia, which is in harmony with De Vries's theory of intracellular pangenesis (p. 11) and if true would enable us clearly to visualize the nuclear "control" of the cytoplasm. Undoubtedly, however, the theory of chromidia has been in large measure discredited by studies on the chondriosomes. This work does not indeed exclude the possibility, even the probability, that visible granules given off from the nucleus may play an important part in the formative processes. The most important of the evidence in this direction seems to the writer to be that produced by Lillie, Conklin and their predecessors in case of the germinal vesicle of the oöcyte. Nevertheless, so far as the Metazoa are concerned it cannot yet be said with assurance that granules having such an origin play an essential part in histogenesis or in other constructive processes of the cell.

The case of the chondriosomes seems much stronger so far as their relation to histogenesis is concerned, though it is still far short of demonstration. That they are independent, self-propagating bodies remains in the main an assumption, supported by a certain amount of definite evidence, but hardly more as yet than a theoretical postulate like Altmann's theory of granules, of which it is no more than a modern development. We should not, therefore, accept the hypothesis of the autonomy of the chondriosomes, still less that of the chromidia and Golgi-bodies, save as an incentive to further cytological study of the phenomena.

III. PROTOPLASMIC STRUCTURE AND METASTRUCTURE

It is an old question whether we may in any measure advance our understanding of the cell-activities by the assumption of an ultra-microscopical organization or metastructure [1] of protoplasm as distinguished from its chemical and molecular constitution. In a speculative form this question long antedates cytology and even the cell-theory itself. The history of our subject impresses us with the great number of eminent investigators, engaged with the most diverse aspects of biological inquiry, who have been driven to the assumption that such a metastructure must exist. Almost without exception this structure has been conceived as having a meristic or particulate character (pangenesis, micromerism, panmerism, etc.), the living substance being assumed to contain, or to be built up from, a multitude of minute discrete corpuscles, which have commonly been assumed

[1] This term is from Heidenhain ('07).

to be of a higher order of complexity than the molecules of proteins and other organic compounds..

The long history of these conceptions can here be indicated only in the most cursory manner.[1] Their prototype appears in Buffon's celebrated theory of "organic molecules," (1804, and earlier) while subsequent to the promulgation of the cell-theory, Henle (1841), and Brücke (1861) seriously considered the possibility that cells might be composed of elementary vital units ranking in degree of complexity between cells and molecules. The first detailed elaborations of such a conception in accordance with more modern scientific ideas include Spencer's theory of *physiological units* (1864), Darwin's celebrated theory of pangenesis (1868), and Nägeli's theory of *micellæ* (1884) which has been widely adopted by botanists. Their climax was reached in De Vries's remarkable and closely reasoned work *Intracellular Pangenesis* (1889), in Wiesner's theory of plasomes (1892), and in Weismann's still more detailed and speculative theory of biophores and the architecture of the germ-plasm (1892). In the nature of the case the primary assumption in all these theories was of purely hypothetical character; for the primary units were in every case assumed to lie beyond the reach of the microscope. Nevertheless numerous investigators in the most diverse fields of biological inquiry were driven to the adoption of the same general type of assumption. We find it in the works of experimental physiologists like Pfeffer, Engelmann; Verworn, or Foster; of students of growth, reproduction and development like Nägeli, Wiesner, O. Hertwig, or Whitman; of investigators in heredity and genetics, such as Darwin and De Vries; of cytologists such as Altmann or Heidenhain; and of more speculative writers such as Spencer, Haeckel and Weismann.

Corpuscular or micromeristic hypotheses of living systems have met with much opposition which, up to a certain point has been justified.[2] Such hypotheses, it has been cleverly said, would make of the world (or the cell) a mere puzzle-picture which we take to pieces only to put it together again, having explained nothing. The emptiness of such a criticism is

[1] A valuable review of them is offered in Delage's *Structure du protoplasma et les théories sur l'hérédité*, etc., Paris, 1903. See also Heidenhain, *Plasma und Zelle*, 1010–11. For earlier reviews and critiques see especially De Vries ('89) and Wiesner ('92). The hypothetical units have received a great variety of names, among which may be mentioned: *Physiological units* (H. Spencer), *gemmules* (Darwin), *pangens* (De Vries), *plastidules* (Maggi, Haeckel, Elsberg, Zoja), *micellæ* (Nägeli) *tagmata* (Pfeffer), *inotagmata* (Engelmann), *microzymas* (Béchamp, Estor), *plasomes* (Wiesner), *biophores* (Weismann), *bioplasts* (Altmann), *gemmæ* (Haacke), *idioblasts* (O. Hertwig), *idiosomes* (Whitman), *somacules* (Foster), *chondria* (Rohde), *protomeres* (Heidenhain). These various names are not strictly synonymous: they represent many different special developments of the general conception; but all agree in the fundamental assumption that "living" matter is an aggregate or congeries of ultra-microscopical bodies which are themselves not molecules but molecular aggregates, in most cases (gemmules, pangens, biophores) assumed to possess the powers of growth and division.

[2] For a criticism of such hypotheses see Yves Delage ('03), Ritter ('19).

obvious in view of the enormous advances of physics and chemistry due to corpuscular conceptions of non-living matter, or of the revolution in biology that resulted from the cell-theory. The reaction against such conceptions of the cell took place because too much was claimed for them, not alone by their advocates but also by critics who wished to destroy them.[1] Opposition was directed especially against the assumption that the "ultimate" particles of protoplasm may be regarded as primary vital "units," capable of autonomous growth or division, as if the cell itself were built up as an assemblage of more elementary organisms. Such opposition is still widespread among competent and critical students of the cell. "The structure of protoplasm," says one of these recently, "is the structure of the cell. The search for some ultra-microscopic structure of living substance as such, and more deep-seated than cell-structure, has so far proved as vain as the older attempts to demonstrate the existence of a vital force."[2]

So far as direct cytological evidence goes such statements are of course well founded. Nevertheless the indirect evidence which both cytology and genetics have been accumulating demonstrates that particulate conceptions of cell-structure, sometimes offer the simplest and most effective means of formulating the observed facts. The experimental study of genetics, for instance, most clearly demonstrates that the germ-plasm must contain great numbers of separate, differential "factors" or "genes," which may independently combine, segregate and recombine; which are self-perpetuating; and which may be transmitted unchanged from generation to generation, subject only to occasional sudden mutations. This was in principle precisely the argument mainly relied on by De Vries thirty years ago in developing his ingenious hypothesis of intracellular pangenesis. More modern hypotheses of this type have in fact become indispensable as a practical means of laboratory analysis, prediction and verification. Attempts have been made, it is true, to explain the phenomena in other ways (*e. g.*, by assumptions of isomerism, molecular regroupings, side-chains, and the like). None of these has been found adequate; and in point of accuracy, simplicity and fruitfulness of method the formulas employed in modern genetic analysis based on the particulate hypothesis almost rank with the atomic and molecular formulas of the physicist and chemist.[3]

The cytologist finds himself constrained by a similar, if less pressing

[1] *Cf.* Wilson ('23).

[2] Harper ('19), p. 274.

[3] These statements are based mainly on the remarkable analysis of Morgan and his co-workers of the immense mass of intricate data collected by them in case of the fruit-fly *Drosophila melanogaster*. See especially Morgan, *The Physical Basis of Heredity*, 1919, and Morgan, Sturtevant, Muller and Bridges. *The Mechanism of Mendelian Heredity*, 1915.

necessity. What rational conception can be formed (as Roux long since urged) of the process of mitosis, with its spinning out of the nuclear substance into long spireme-threads, and their *longitudinal fission*, if this be not a device by which different nuclear elements are aligned in orderly series and equally divided? Were division the merely physical separation of colloidal threads into equal parts we should, assuredly, expect them to divide transversely. How shall we draw any logical line of demarcation between dividing plastids, which are often of considerable size, and still smaller bodies that may have similar powers? Centrioles, for example, are known to have the power of self-perpetuation by growth and division though they are so minute as to lie almost at the limit of microsopical vision. When, therefore, they seem to make their appearance *de novo* in the hyaloplasm it is entirely possible that they may preëxist in a form too minute to appear above the horizon of visibility. The reality of the question here raised is attested by the ultra-microscope, which demonstrates the existence of numerous particles suspended in the protoplasmic substance (as in a colloidal solution) and beyond the reach of direct microscopical vision; further, by the supposed existence of ultra-microscopical germs, such as those of measles, the foot and mouth disease of cattle, and others which will pass through a fine Berkefeld filter and are invisible by the microscope, yet are capable of indefinite multiplication without loss of their specific character (as proved by laboratory cultures and inoculations).[1]

Altmann at first identified the essential, living structural components of the cell-substance with the *visible* granules or "bioblasts" (p. 75). Later, as a result of studies on the history of the granules, especially in gland-cells, he extended this view:

> "Evidence has been obtained from many sources to show that the larger granules lying in the meshes of the network take their origin from smaller ones which lie in the substance of the net itself, and may there arise from still smaller forms which, perhaps because of their minuteness and other properties, have not yet been made visible. As the small granules in the course of their vital metabolism (assimilation) give rise to and store up in themselves proteins, fats, carbohydrates, they increase in size and change their staining reactions through the reduction of their own living substance. They thus effect the transportal of nutritive substances in the process of reabsorption; in secretion they are cast out as secretory granules which form the essential component of the secretion; while in the intermediate stages of transformation they often constitute deposits of reserve substance. This we see most conspicuously in the fat cells and in the nutritive yolk of the egg, but in less extreme degree the same may be observed in almost all forms of cells." [2]

Somewhat akin to this was the conception of the alveolar structure of protoplasm suggested by the work of G. F. Andrews ('97) [3] who recognized

[1] Cited from Jordan ('11).
[2] 94, pp. 16, 17.
[3] See also Wilson, '99.

in the alveolar protoplasm of the sea-urchin that the interalveolar or "continuous" substance (hyaloplasm) is itself alveolar on a smaller scale, *i. e.*, contains numerous minute granules or drops ("microsomes") which graduate in size down to the limits of microscopical vision, as is seen with especial clearness during the progressive development of the alveolar structure (p. 73). Manifestly, however, the limits of microscopical vision are purely artificial. The cytologist, therefore, finds it difficult to escape the conclusion that in respect to their size and degree of dispersion the visible and the invisible components of the protoplasmic system form a continuous series.

The conception of Heidenhain is very similar to Altmann's: "We must logically conclude that these (the secretory granules) do not arise *de novo* in the cell-body by a kind of *generatio equivoca* . . . but must themselves be derived from (preëxisting) components of the cell-substance. But since the primary granules appear at the limits of visibility we are necessarily again brought back to Altmann's view, that the granules in their first beginnings have their origin in the protoplasmic matrix (*i. e.*, hyaloplasm), of the cell. . . . The granules, accordingly, take their first origin from the smallest, meta-microscopic living particles, which acquire a certain degree of independence, and by assimilation, growth and corresponding metathesis of their substance become converted into the histological (visible) granules." [1]

In this conception the fundamental problem of protoplasmic structure passes over into that of the colloidal state. It should not be taken to imply that the dispersed particles of the hyaloplasm necessarily are self-perpetuating, elementary living "units" or "protomeres" as postulated by earlier micromeristic theories. To the writer, however, it would seem a backward step wholly to reject the possibility that some or many of these particles may have the power of perpetuating their own specific type, as is known to be the case with some of the visible formed components of the cell. Could we accept such a view we could more readily meet some puzzling difficulties such, for example, as the apparent contradiction between the origin of a centriole *de novo*, and its origin by division of a preëxisting body of the same kind.[2]

The alveolar structure of protoplasm is obviously an emulsoid or suspensoid formation, which repeats on a large scale some of the features of a "homogeneous" colloid. In this visible structure we are not dealing with a simple diphasic system but with a compound or polyphasic system, often of great complexity, the discontinuous or disperse phase being represented

[1] '07, p. 396.
[2] Wilson ('99, '23).

by bodies of great chemical and physical diversity. Some of them are independent organellæ, active elements, such as plastids, centrioles or mitochondria, possessing the powers of independent assimilation and growth, and in some cases also of division. Others are in various degrees more passive, having arisen perhaps by the direct transformation of more active elements, and in extreme cases converted into true metaplasmic, ergastic or paraplasmic structures, such as drops of water or fat, starch grains, or yolk-spheres.[1] Somewhat like this larger picture in miniature we may perhaps imagine the metastructure of the hyaloplasm which lies below the horizon of our microscopical vision. That it is not wholly imaginary seems to me to be indicated alike by the ultra-microscope, by studies on the protoplasmic colloids, and by cytological observation. We should not emphasize unduly the analogy between such a metastructure and the cellular structure *of the tissues* (as has often been done by earlier writers on the speculative side of this subject). It is a highly theoretical question whether we can rightly speak of protoplasm (hyaloplasm) as being "built up" of self-perpetrating protomeres; and it must be borne in mind that protoplasm is not, like most tissues, a relatively rigid system, but is in a state of continual flux. The conception that has been indicated may be of practical value in so far as it aids practically in investigation,[2] and may serve to put us on guard against too simple a formulation of these problems from the standpoint of physical and colloidal chemistry.

IV. DUALISTIC CONCEPTIONS OF THE CELL-SUBSTANCE

We may here briefly consider certain dualistic conceptions of the cell-substance that have considerably influenced the development of modern cytology. If none of them have been entirely successful they are none the less of interest considered as efforts to bring together the physiological and the morphological aspects of cell-phenomena.

The earliest attempts in this direction, of very general character, did not distinguish specifically between nucleus and protoplasm. Here belongs Beale's distinction (p. 58) between living, formative or "germinal" substance (bioplasm) and secondary or formed products (*formed matter*). Here too may be placed Nägeli's theory of the idioplasm (1884) which has exercised an important influence on our conceptions of heredity. Nägeli conceived the organism as composed fundamentally of two living substances or plasmas. One, constituting the main bulk of the protoplasm, is a vegetative or nutritive *trophoplasm* ("*Ernährungsplasma*"), in which are carried

[1] *Cf.* A Meyer's grouping of the cell-components as protoplasmatic, alloplasmatic and ergastic (p. 58).

[2] H. V. Wilson ('16, p. 14).

on the main operations of nutrition and metabolism. The other, present in much smaller quantity, is a generative *idioplasm* that plays a leading rôle in reproduction and development and constitutes the physical basis of heredity (p. 1037). This hypothesis was elaborated with an acuteness and skill that still commands our admiration, and though it cannot be upheld in the original form it has proved itself to be one of the most fruitful conceptions of modern biology.

1. The Cytoplasm. Archiplasm, Kinoplasm, Morphoplasm and the "Superior Protoplasm"

The first clearly formulated hypothesis of cytoplasmic dualism appears in Boveri's much discussed conception of the *archiplasm*. By this term (originally written *archoplasm*) Boveri designated the material of the spindle-fibers and astral rays, at first conceived as a permanent substance, distinct from the general cytoplasm of the resting cell but scattered through it in the form of specific granules.[1] Subsequently ('95) this view was modified by the conclusion that neither the archiplasmic fibrillæ nor the granules are permanent structures but formations which come and go with different phases of the protoplasmic activity.[2] Boveri still held, however, that the archiplasm might preëxist as a specific, homogeneous substance which, though not ordinarily visible, may become so by taking on the form of granules or fibrillæ that crystallize, as it were, in the preëxisting protoplasmic framework. In this form the hypothesis is close to the *kinoplasm* hypothesis of Strasburger ('92 and later) which has enjoyed a wide repute among botanists.

Strasburger conceived protoplasm to consist of—or to have a marked tendency to transform itself into—two distinct substances, *trophoplasm* and *kinoplasm*, which differ characteristically both physiologically and structurally. The kinoplasm (earlier called "formative protoplasm") was assumed to be an especially active and irritable substance that forms the astral rays and spindle-fibers, the central bodies, the plasma-membrane, and the contractile material of cilia and flagella. Morphologically, it shows a marked tendency to assume a fibrillar structure; hence the term *filar plasma*. On the other hand, the trophoplasm (which, like Nägeli's trophoplasm, constitutes the main mass of protoplasm) is the seat especially of the nutritive processes and tends to assume an alveolar structure.

[1] '88, 2, p. 80.

[2] It has been shown, especially by Meves, that the archiplasmic granules, as described by Boveri in *Ascaris*, were probably nothing other than mitochondria. Meves clearly shows, further (here confirming Boveri's later account), that these granules do not give rise to the astral rays or spindle-fibers but lie between them. Lams ('10) contributes interesting details concerning the concentric zones of mitochondria in the snail *Arion* (*cf.* p. 683).

Later writers extended the conception both of archiplasm and of kinoplasm so as to include a great variety of other cell-components. In the meantime arose a third related conception, that of the *ergastoplasm*, due to Garnier ('97, 98) and P. and M. Bouin ('98, '00) and subsequently developed by Maziarsky ('03), Prenant ('04) and others. This term was applied to the substance of the fibrillar formations characteristic of many gland-cells and also to certain flocculent masses or other formations, described under this name by the Bouins ('98) in the embryo-sac of the lily, in the oöcytes of the starfish, the spermatocytes of *Lithobius* ('99) and elsewhere. Ergastoplasm was regarded by these observers as a specific and dominant protoplasm ("*d'essence supérieur*"), of which the most characteristic property is its power of elaborating and transforming the various substances laid down in the cell.

Out of the foregoing conceptions grew the more general one developed by Prenant ('98, '99, '10) of a "superior protoplasm" which plays a leading rôle in the cell-activities generally. Archiplasm, kinoplasm, ergastoplasm were conceived as closely related but slightly differing forms of this substance, which is physiologically the dominating and most active element. Its tendency to assume the fibrillar type of structure (spindle-fibers, astral rays, glandular fibrillæ, myofibrils, neurofibrils, fibrillæ of ciliated cells, etc.) and to stain energetically with basic dyes, led Prenant to speak of it as a kind of "cytoplasmic chromatin" or "cytochromatin." We need not follow the development of this conception in detail since in Prenant's final development of the subject ('10) the formed components of the cytoplasm generally are excluded from the "superior protoplasm." "Is the really primitive and superior protoplasmic substance that which exhibits a particular structure and staining reactions? Is not the superior protoplasm, on the contrary, represented by the formless and non-staining substance, that of which we know least, yet in which take place the most intimate phenomena of life?" In common with so many other cytologists, therefore, Prenant is finally driven to seek the fundamental basis of the protoplasmic system in the "structureless" hyaloplasm, and the theory of superior protoplasm becomes hardly distinguishable from Beale's early conception of the living "bioplasm" as distinguished from the "formed" components of the cell-substance.

To the writer, the history of modern cytology seems clearly to show the futility of all dualistic hypotheses of the protoplasm, save as convenient descriptive devices. Every such hypothesis has broken down when based upon the postulate of two fundamentally and permanently different substances. For the purpose of description it is often convenient to employ such terms as "trophoplasm," "archiplasm," "kinoplasm," "ergastoplasm"

and the like; but in view of the theoretical connotation of all these terms it seems preferable to avoid their use wherever practicable.

2. The Nucleus. Trophochromatin and Idiochromatin

Dualistic conceptions of the cytoplasm have been paralleled by analogous ones concerning the nucleus, based on the frequent appearance of two different forms of "chromatin," which may even be contained in separate nuclei. The two substances in question are assumed to be concerned, respectively, with the metabolic, vegetative or trophic activities, and with the generative or reproductive. Various names have been applied to them; for instance *trophochromatin* and *idiochromatin* (Lubosch); *somatic* and *propagatory* chromatin (Goldschmidt); *trophic* and *gametic* chromatin (Dobell) etc. This conception shows a certain analogy to Nägeli's above-mentioned distinction between trophoplasm and idioplasm; but its real germ appears in Weismann's early distinction between "histogenetic" or "ovogenetic" plasm and "idioplasm," considered as two different forms of nuclear substance or "karyoplasm." [1] Later the hypothesis gradually took more definite shape along two somewhat different lines of development, one starting from the history of the nuclear substance in mitosis and maturation and the phenomena of "diminution" in the formation of the germ-cells in higher organisms (p. 323), the other from studies on the general history of the chromatin in Protista.

We first consider an hypothesis of chromatin dualism especially associated with the names of R. Hertwig, Schaudinn, Goldschmidt and Popoff, though many others have contributed to it. Many observers have laid stress on the fact that in the prophases of mitosis, and especially in the prophases of the egg-nucleus in preparation for the maturation divisions, a considerable quantity of the nuclear material is eliminated from the nucleus, either becoming transformed into spindle-fibers or being cast out bodily into the protoplasm. As earlier indicated (p. 269) the definitive chromosomes are often differentiated from the general network at a very early period in the growth of the egg; and a large part of the network is cast out as a residual substance into the body of the cell when the nuclear membrane breaks down (p. 355). This naturally suggests that the residual substance is especially concerned with the trophic functions of the egg during its long period of growth (the "ovogenetic plasm" of Weismann) while the "true chromatin" or idioplasm is passively awaiting the formation of the spindle.[2] The two constitutents of the germinal vesicle would thus be comparable respectively to the two forms of nuclei in the ciliates, *i. e.*, the macronuclei,

[1] P. 498, Essays, II, IV.

[2] See Rückert ('92, '93), Gardiner ('98), Griffin ('99), etc.

mainly concerned with the metabolic and vegetative activities of the animal, and the micronuclei, which constitute a reserve of "idioplasm" or generative chromatin. A similar conclusion is strongly suggested by the phenomena of "diminution" during the history of the germ-cells (p. 323). It seems impossible to doubt that in these cases the nucleus for the time being contains two different substances, a primary and essential component which alone is transmitted by the chromosomes, and a derived and secondary one the functions of which have come to an end.

A related conception grew out of the researches of R. Hertwig, Schaudinn and others on the formation of chromidia in the rhizopods as above described (p. 700). Schaudinn considered the principal nucleus (or nuclei) in the rhizopods as a "vegetative" nucleus consisting of "metabolic nuclear substance," which represents the macronucleus of ciliates, and like the latter degenerates with the onset of the sexual activity (p. 608), while the chromidia given off from it, and from which the gamete-nuclei arise, are composed of "sexual" or generative chromatin, and correspond in this respect to the micronucleus.[1] In the ciliates the two substances are contained in separate nuclei throughout the whole vegetative cycle; in other forms they are united in a single nucleus and only separate under pathological conditions or in the stages preceding conjugation. Thus arose the much discussed "binuclearity hypothesis" of Goldschmidt and his followers,[2] according to which every cell may be regarded as containing a "somatic" nucleus, composed of *trophochromatin* and a "generative" or "propagatory" nucleus composed of *idiochromatin*. As a rule the two are united to form an "amphinucleus." Their separation is commonly affected by a giving-off to the cytoplasm of chromidia which may be either generative (*idiochromidia*) or somatic (*trophochromidia*).[3] In the cells of Protozoa the chromidia may be of either type; for example, those of *Actinosphærium* formed during periods of starvation are somatic, while those of *Arcella* (p. 701) are *generative*, ultimately giving rise to the gamete-nuclei. In metazoan cells only somatic chromidia were assumed to occur, the generative chromatin being confined to the formed nuclei. Complete separation of the two kinds of chromatin in different nuclei is seen only in Protozoa (ciliates). In Metazoa the separation is but temporary and rarely complete. This hypothesis was given a still broader development in a later paper by Goldschmidt and Popoff ('07).

This hypothesis is open to the same general criticism as the hypotheses of cytoplasmic dualism already considered. It was much weakened by

[1] '03, p. 553.
[2] See especially Goldschmidt ('04), Goldschmidt and Popoff ('07).
[3] Mesnil ('03).

later studies proving that many of the so-called "chromidia" in metazoan cells are mitochondrial formations having no connection with the nucleus (p. 703). Further, unless the assumption that "every animal cell is by nature binucleate" be taken as a mere figure of speech, or in a purely transcendental sense, it must imply that the generative and trophic chromatins are definite and distinct entities. Such an assumption, however, collapses in face of the fact that both chromatins originally arise from the chromosomes which, by the hypothesis, consist of generative chromatin. At best, therefore, trophic and generative chromatins can only be regarded as different phases or modes of activity of one original substance.[1] Another development of the hypothesis of binuclearity with reference to the historical origin of the division-centers is considered in a following section (p. 735).

V. THE KARYOPLASMIC RATIO

We digress at this point for some further consideration of the quantitative relations between nuclear mass and cytoplasmic mass which have been briefly reviewed in Chapters I, III and VIII. The development of the theory of the karyoplasmic ratio by Hertwig ('03, '08, etc.) and his followers was undoubtedly carried too far; but there remain well-determined facts concerning this ratio that are of interest for many cell-problems. It is important not to confuse the maintenance or modification of the karyoplasmic ratio under normal conditions with that due to artificially induced changes. The maintenance of the normal relation is well illustrated in the cleavage of the ovum in such forms as annelids or gasteropods, where very marked inequalities of division often occur. In all such cases nuclear division is exactly equal so that all the cells receive equal amounts of chromatin. After the nuclei are re-formed, however, the nuclei grow to a size that is roughly proportional to that of the cytosome.[2] In cases of this type the size of the nuclei is obviously regulated by that of the cytosome. A conclusion similar in principle was afforded by certain experiments on dwarf larvæ of sea-urchins arising from isolated blastomeres or egg-fragments in sea-urchins.[3] In dwarf larvæ of different size, arising from isolated blastomeres of the 2- or 4-cell stages, the cells are of nearly or quite the same size but differ in number, the ½-larvæ containing about one-half, and the ¼-larvæ about one-fourth the normal number characteristic of an entire egg at the corresponding stages. Conversely, in giant larvæ produced

[1] An effective criticism of the hypothesis is given by Dobell ('09), *Cf.* also Minchin ('12), Duesberg ('12), and Swezey ('16).

[2] This was first clearly indicated by Conklin ('02) though, as he later especially emphasized ('12), a wide variation exists in this relation.

[3] Morgan ('95, '01, '03), Driesch ('98, '00), Boveri ('05).

from two fused eggs, the number of cells is double the normal number (Driesch). In all these cases the result is brought about by an adjustment of the cleavage-process to the size of the embryo; the smaller the original piece the fewer the cleavages required to produce cells and nuclei of the proper size. Morgan and Driesch thus reached the conclusion that the cleavage is so regulated as to produce a fixed or typical cell-size at a given

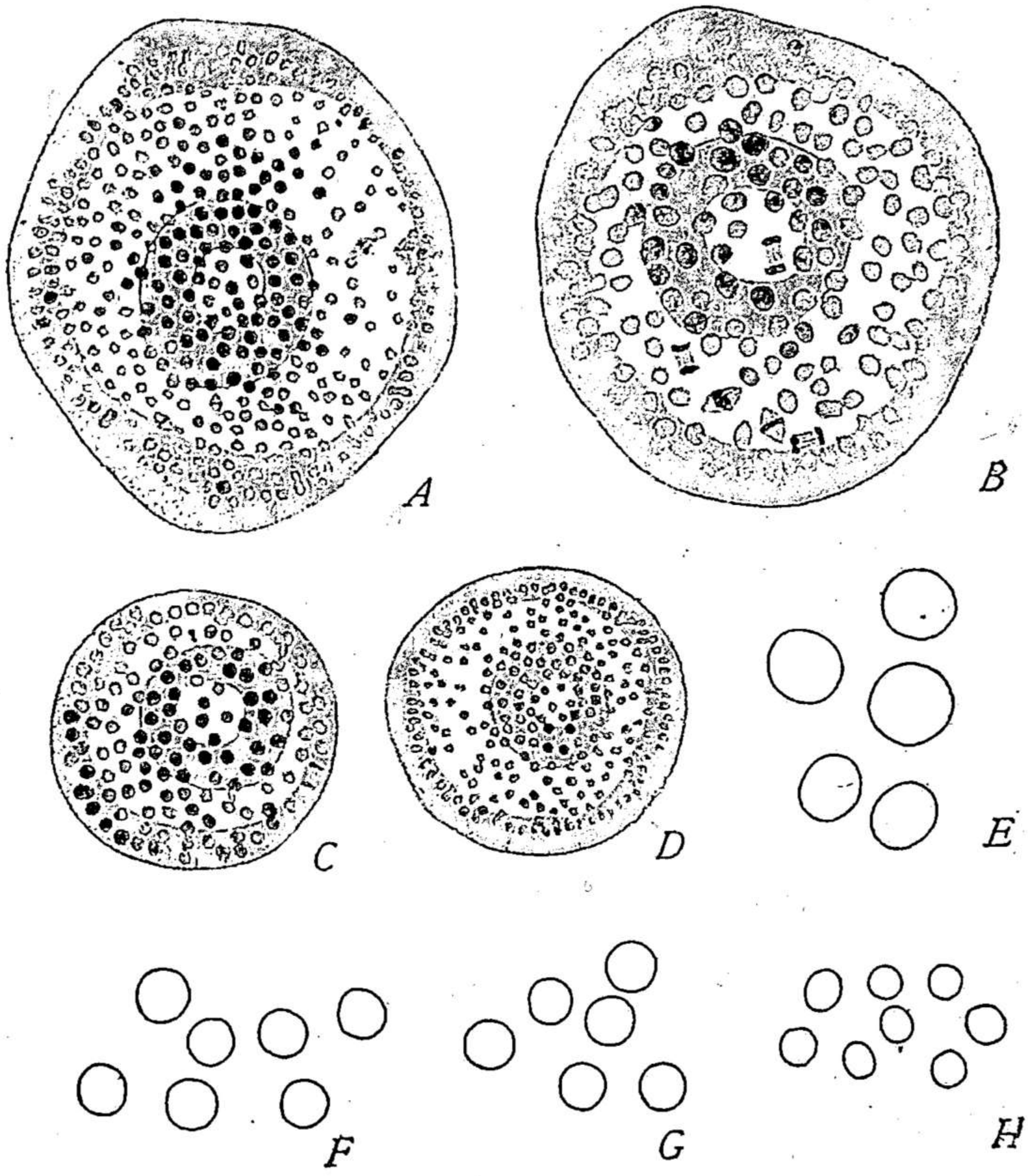

Fig. 349.—Karyoplasmic relation in embryos of the sea-urchin *Paracentrotus* (BOVERI) *A*, normal diploid (amphikaryotic) gastrula, from upper pole; *B*, corresponding view of tetraploid (diplokaryotic) gastrula at the same stage (from a monaster-egg); *C*, normal diploid dwarf gastrula, from an egg-fragment; *D*, corresponding stage of haploid (hemikaryotic) dwarf, from merogonic egg-fragment; *E–H*, more enlarged nuclei from larvæ of various types drawn to the same scale; *E*, tetraploid (from *B*); *F*, diploid (from *C*); *G*, diploid (from *A*); *H*, haploid (from *D*).

stage rather than a fixed number of cells; and this was afterwards confirmed by Boveri.

In the foregoing cases the volume of the nucleus varies primarily with that of the cytosome or cytoplasmic mass. Equally interesting is the reverse case in which the primary variable factor is the nuclear mass. Typical cases are offered by the tetraploid giant forms of *Spirogyra*, *Œnothera*, *Primula* and *Solanum*, already mentioned (p. 656), in which the nuclear

volume is doubled as a result of a doubling of the number of chromosomes, and the normal karyoplasmic ratio is restored by a corresponding growth of the cytosome to twice its former size. The classical experiments on this subject are those of Boveri ('05, '07) on sea-urchin eggs in which the number of chromosomes may readily be altered experimentally in several ways, as follows: (1) In artificially parthenogenetic eggs (p. 476), or in merogony (p. 465) the number of chromosomes is haploid; (2) in the normal fertilized egg the nucleus is diploid; (3) by shaking the normal egg near the time of the first cleavage the first mitosis of the egg is often rendered monocentric,

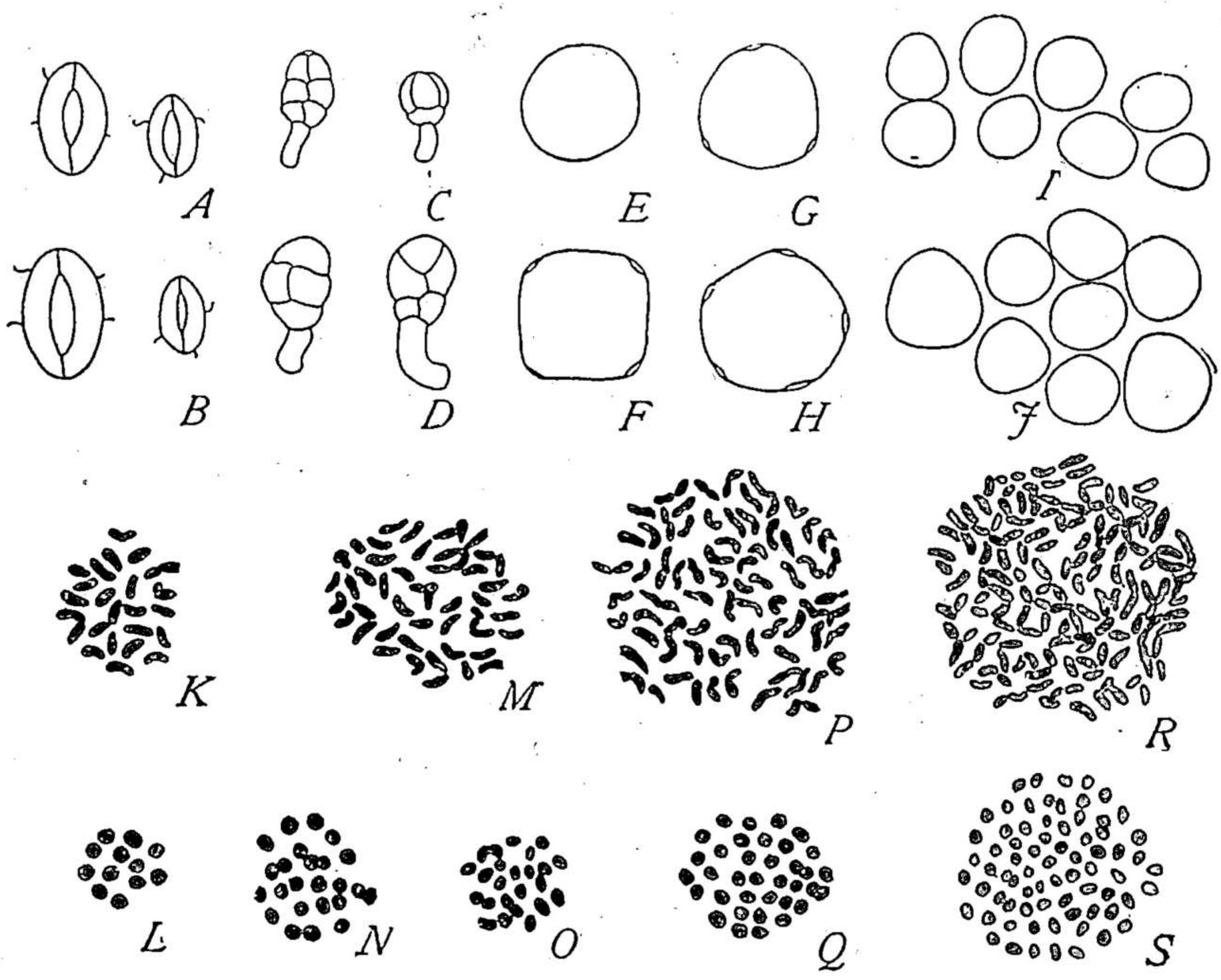

Fig. 350.—Chromosome-number and cell-size in *Solanum* (WINKLER).

A, stomata from normal diploid nightshade (*Solanum nigrum*); *B*, from *gigas tetraploid* mutant of same; *C*, *D*, corresponding views of calyx-hairs from the two forms; *E*, *F*, and *G*, *H*, pollen-grains of the two forms; *I*, chloroplasts from the tomato (*S. lycopersicum*) and *J* from its *gigas* mutant; *K*, somatic diploid chromosome-group from normal tomato (*S. lycopersicum*), 24 chromosomes. *L*, pseudo-haploid group (heterotypic division) from *S. Koelreuterianum* (*Lycopersicum* type) 12 bivalents; *M*, normal tetraploid somatic group from root-tip, *gigas* form (from *S. Koelreuterianum*); 48 chromosomes; *N*, pseudo-haploid group (heterotypic division), 24 bivalents; *O*, haploid group of same, second sporocyte-division, 24 chromosomes; *P*, normal haploid somatic group of *S. tübingense* (*nigrum* form), 72 chromosomes; *Q*, pseudo-haploid group of the same (heterotypic) 36 bivalents; *R*, normal tetraploid somatic group of *gigas* form of last, 144 chromosomes; *L*, pseudo-haploid group of same (heterotypic division) 72 bivalents.

and the number of chromosomes is doubled without division of either nucleus or cell-body (p. 168). Such eggs may later divide normally and produce larvæ in which the chromosome-groups are tetraploid; (4) in dispermic eggs the number is originally triploid, but by the resulting multipolar mi-

tosis the larval nuclei usually come to have varying numbers of chromosomes (p. 919).

Boveri demonstrated with great clearness that the size of the nuclei at any given stage is directly proportional to the number of chromosomes that they contain; they are smallest in the haploid larvæ, largest in the tetraploid, and of varying size in the dispermic ones (Fig. 349). Here again, however, as in *Spirogyra*, the normal nucleoplasmic ratio may sooner or later be restored by a regulative process, effected in this case by modification in the number of cleavages, this number being increased in the one case, decreased in the other (p. 727) so that larvæ with smaller nuclei have also smaller cells, and *vice versa*. It is interesting to compare this result with those of Driesch and of Morgan on isolated blastomeres and egg-fragments, referred to above. In the latter the primary variable factor is the total size of the embryo, the size of both nuclei and cells remaining normal. In Boveri's case, on the other hand, the primary factor is the number of chromosomes which leads to corresponding variations in the size of the nuclei and of the cells. In both cases the regulative factor is the process of cleavage, by which the normal nucleoplasmic ratio is maintained. In Boveri's words: "The constant, which we must accept as something given and not at present further analyzable, is the fixed proportion between nuclear volume and protoplasmic volume, namely, the karyoplasmic ratio" ('05, p. 68).

Boveri's extensive measurements led him to the unexpected result that in the sea-urchin, with increasing chromosome-number the nuclear volume increases more rapidly than the cytoplasmic, in such a manner that it is the *surface* of the nucleus and not its volume that is directly proportional to the number of chromosomes. This result seems to be confirmed by the subsequent work of Baltzer ('09) and of Herbst ('12, etc.) on sea-urchin eggs, and also by that of Artom ('11a, '11b, '12) on the phyllopod *Artemia salina*. Two races of this species are known, *A. salina uni-* and *bi-valens*, the former having 42 chromosomes (diploid number), the latter 84 (p. 231). Here again the surface-area of the nucleus was found to be approximately proportional to the number of chromosomes.

On the other hand, Gerassimoff found in *Spirogyra* (Fig. 313) that in the giant forms both nucleus and cell-body have approximately double the volume of the normal, though a considerable range of variation exists; and the same result has been reached by a number of others. An interesting example is offered by the studies of É. & É. Marchal ('09, '11), on artificial apospory in mosses (Fig. 407). Haploid nuclei are found in the normal gametophyte, diploid in the aposporic gametophyte generation derived by regeneration from the diploid sporophyte (p. 746). In the dicœcious mosses

such diploid gametophytes are completely sterile, but in some of the monœcious forms (*e. g.* in *Amblystegium repens*) they are fertile, producing diploid gametes, which unite to form tetraploid zygotes and sporophytes. From the latter finally by regeneration (artificial apospory) are obtained tetraploid gametophytes.[1] Measurements of these various cases show that the mean *volume* of both nuclei and cells is directly proportional to the number of chromosomes. This applies alike to somatic cells (of the leaves and of the antheridial tissues) and germ-cells, including both spores and eggs; in each case the diploid nuclei and cell-bodies are approximately twice, and the tetraploid four times the volume of the haploid. It does not appear from the Marchals' memoir that the same rule applies to the plant as a whole, *i. e.*, giant races seem not to be formed. Nevertheless, the reproductive organs (antheridia, archegonia) conform approximately to the rule. In *Amblystegium*, for instance, the length and breadth of the archegonia, in microns, are in the normal haploid race 248:46, in the diploid race 306:50, and in the tetraploid 456:83.

A somewhat similiar result was reached by Gates ('09) in a study of the tetraploid giant *Œnothera gigas*, in which the nuclei are on the average twice the volume of those of the diploid parent from *Œ. lamarckiana*, the plant as a whole being likewise larger in nearly all its parts, including the seeds.[2] Results similar in type have been reported by Tischler ('10) in races of bananas having respectively 8, 16, and 24 chromosomes, by Nemec ('10) in artificially produced tetraploid cells of root-tips, by Winkler ('16) in giant tomatoes and night-shades (Fig. 350) and by other observers.[3]

It is however, certain, that in some forms the karyoplasmic ratio is subject to wide variation, as is strikingly shown by Conklin ('12) in the cleavage-stages of *Crepidula*. In this case, it is true, large cells usually have larger nuclei than small; but the ratio varies widely with the length of the interkinesis and in the amount of yolk material. In *C. plana*, for example, the ratio of cytoplasmic to nuclear volume in protoplasmic cells free from yolk, and measured at their maximum size, varies from 14.5 to 8.7, or from 35.7 to 7 when measured at their mean size. In *Fulgur* at mean size it varies from 127.7 to 3.6. Conklin also showed that the nuclear volume varies not with the total volume of the cytosome but only with that of its active protoplasm. This is proved by eggs centrifuged during cleavage, in which a sharp separation takes place between the heavier yolk and the lighter protoplasm, so that their volumes may readily be determined. In such eggs,

[1] The experiment cannot be carried beyond this point owing to the complete sterility and general weakness of the tetraploid plants.

[2] Gates found the relative volumes of the cells to vary considerably, those of the giant ranging from 1.44 to 3.84 times the normal diploid.

[3] *Cf.* p. 100.

during cleavage, it may readily be seen that the largest nuclei appear in blastomeres that contain the largest amount of active protoplasm, *irrespective of their total size*. This is shown in Fig. 351, where the largest nuclei are actually situated in the smallest cells.

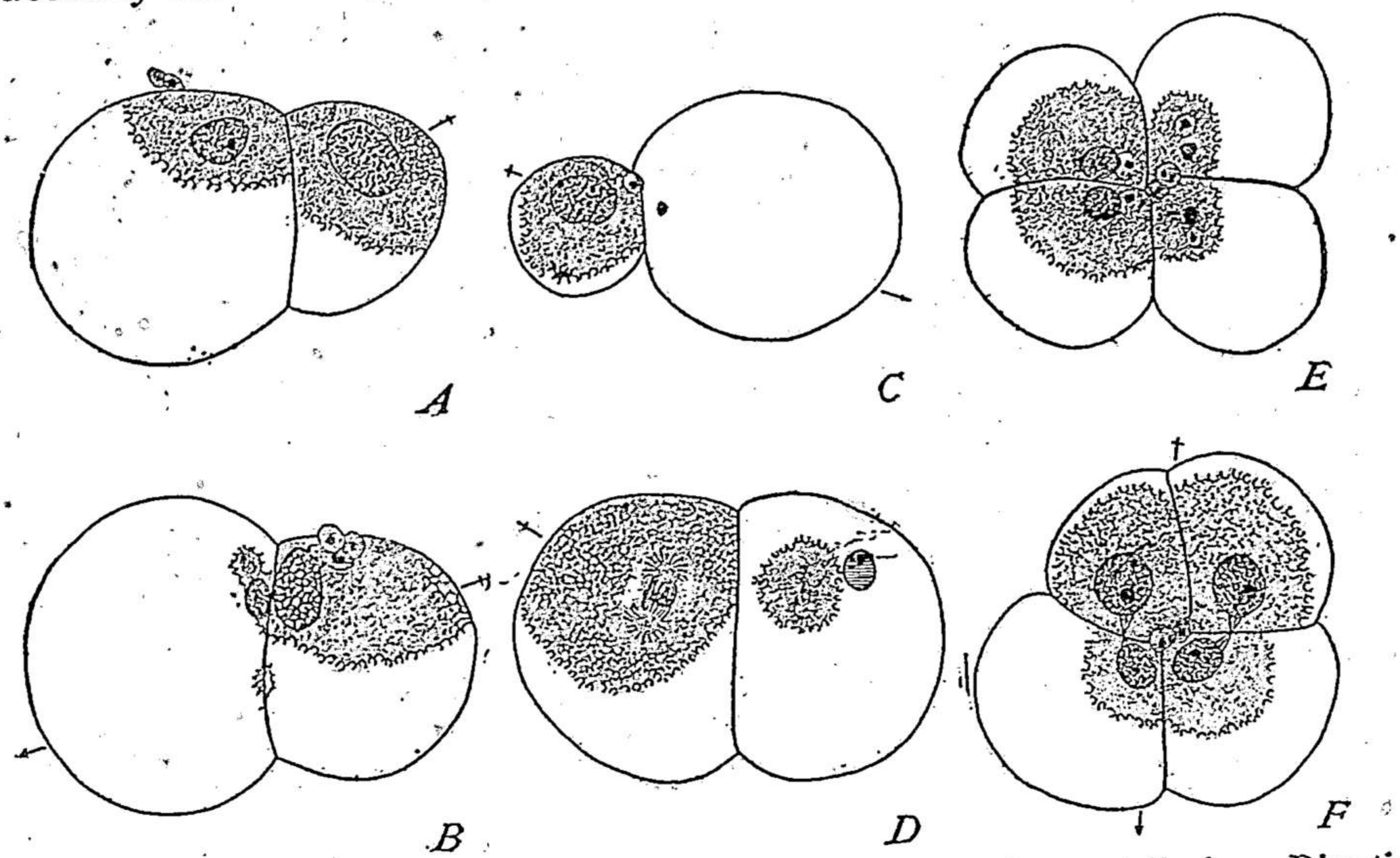

Fig. 351.—Karyoplasmic relation in segmenting eggs of *Crepidula* after centrifuging. Direction of the centrifugal force shown by arrows (CONKLIN).

In each of these 2-cell and 4-cell stages the nuclear size is proportional to the amount of active protoplasm (stippled), not to that of the cell as a whole.

These various facts, together with those earlier considered show that although the karyoplasmic ratio is a real and important cell-constant it results from a complex of factors often difficult to analyze. It calls, therefore, for critical treatment in all attempts to employ it as a factor in age, cell-division or the like or as a guide to the number of chromosomes that have entered into the composition of the nucleus (p. 236, etc.).

Finally, the remarkable fact may be emphasized that not only the nuclear size but also that of the formed components of both nucleus and *cytosome* often varies proportionately to that of the cytoplasmic mass. This is seen in the mitotic figures of dividing blastomeres and the centrosomes or "centrospheres" of the interphase (Conklin, '02, '12); in the centrioles, chondriosomes, acroblast and chromatoid bodies (p. 304); and in the plastids (p. 656). These differences evidently result from the increased size of the cytosome, however caused; for they appear in the polymegalous spermatocytes of insects, which are diploid (p. 304) as well as in the tetraploid cells of *gigas* forms (p. 656). The fact may also here be recalled that the size of the plasmosomes varies with that of the cytosome and nucleus (Montgomery), and that the same is true in certain cases of the chromo-

somes (during cleavage, p. 237), though this seems not to be invariable (*cf.* p. 304). The interesting problems here offered should repay further study.

VI. HISTORICAL PROBLEMS OF THE CELL [1]

Cells, like the more complex organisms that they may build up, undoubtedly owe their existing characteristics to an historical process of transformation; they too have undergone a process of evolution. Of its early course we have no direct knowledge; nevertheless, we may permit ourselves certain harmless conjectures concerning their later development.

In some directions, as has briefly been indicated in the foregoing pages, a certain amount of light has been thrown on the probable evolution of cells. Evidence has been cited to show, for instance, that mitosis of the more complicated forms has been derived from simpler types; that the central bodies were originally intra-nuclear; that fertilization in higher plants and animals is probably a survival of a process of conjugation in remote ancestral unicellular forms; that the highly differentiated types of gametes have arisen from more generalized ones, probably motile and of similar external form in both sexes; that the vesicular and massive types of nuclei have probably arisen from those of scattered or chromidial type; and so on. Degressive as well as progressive changes have undoubtedly taken place: examples of this are offered by the loss of asters and central bodies in the anastral types of mitosis in higher plants and animals; the production of non-motile sperms in various groups; the loss of chlorophyll in the gametes of higher plants.

It is now rather generally accepted that the more primitive types of cells were very probably devoid of an *individualized* nucleus, *i. e.*, that the nuclear materials were originally scattered through the cell in the form of chromidia-like bodies which only at a later period became aggregated to form a nucleus of the ordinary massive or vesicular type.[2] This view finds its support in the present existence of various forms among the Protista in which the nuclear material is actually thus distributed through the cell, and by the fact (if existing accounts are correct) that in some of these forms individualized nuclei may arise either by enlargement of the individual chromidia or by their aggregation into a granular mass, in the processes of gamete-formation, mitosis, or spore-formation (bacteria).[3] We may plausibly assume that this first occurred as a temporary process preparatory to

[1] The author acknowledges his indebtedness in the preparation of this section to the interesting discussions of Strasburger ('09) and of Minchin ('15). Some of the problems here considered may more readily be understood after a reading of Chapters XI and XII.

[2] *Cf.* Strasburger ('09), p. 115, Minchin, ('12, '15, p. 22), etc.

[3] *Cf.* pp. 83, 700.

reproduction, later becoming established as a more permanent feature of the cell though still capable of returning to the chromidial state, as seems still to be the case in some Protista. If this be correct it seems probable, further, that the scattered chromidia from which individualized nuclei arose were self-perpetuating, *i. e.*, that the chromidial substance maintained itself by some process of growth and division referable to the granules as such.

Minchin in particular ('12, '15) has developed in some detail the view that the most primitive of existing nuclei were simple aggregates of chromatin-granules (forming the so-called "karyosome" of protozoan nuclei) surrounded by a protoplasmic vacuole, but not bounded by a definite membrane other than the surface-film or plasma-membrane such as probably forms the boundary of all vacuoles. Such a nucleus, exemplified by those of various small *Amœbæ* of the *limax* type, has been called a "protokaryon." From it as a point of departure may plausibly be derived vesicular nuclei, bounded by a well-marked nuclear membrane, inclosing a large chromatin-nucleus and surrounded by a nuclear cavity containing chromatin. In the earlier stages all the chromatin (or chromosomes) may be assumed to have been confined to the karyosphere, later to have extended into the peripheral zone (originally the vacuole); and by a final step to have abandoned the karyosphere entirely, the latter now forming an intra-nuclear division-center or "nucleolo-centrosome." All these stages, as earlier indicated, exist among *Amœbæ* of the *limax* type (p. 207).

The incipient nucleus may be assumed to have been traversed by an achromatic (*i. e.*, *cytoplasmic*) framework in which the chromioles were suspended; and from this arose the linin network and the nuclear membrane, while the enchylema filling its interstices became the nuclear sap. The nucleus may thus be conceived as arising from a limited area of the cytoplasm, into which are crowded the original chromidia, surrounded by a membrane produced from the cytoplasmic substance. It may be assumed that at this stage chromosomes and mitosis in the strict sense of the words had not yet arisen, and that nuclear division was of simple type, involving no more than division of the chromioles and the separation of the products into two approximately equal groups by an amitotic process such as may still exist in many of the simpler types of Protista.

It was, perhaps, at this stage of the evolution, perhaps earlier, that the process of syngamy arose, as a consequence of inequalities in the distribution of the cell-substance compensated by subsequent processes of cell-fusion (p. 616); but this is purely hypothetical. In any case we may assume the next step to have been the origin of mitosis, which involves two major problems. One of these is the origin of chromosomes, a process which undoubtedly occurred during the unicellular stage of evolution. We may

conjecture that this first involved a linear aggregation of chromioles to form spireme-threads; and we are driven to the further assumptions that with the appearance of syngamy and the consequent phenomena of meiosis the chromioles underwent a progressive qualitative differentiation and gradually assumed a definite serial order. To cite Strasburger: "So long as a simple mode of division suffices to ensure the proper distribution of all the units, it is not noticeably complicated. This changes with increased diversity among the units and attains its climax when each unit is devoted to a single function. An equal, qualitative division of the nucleus now demands that during division the units assume a linear alignment in threads, separation of the products being effected by longitudinal splitting of the thread. This must have been the only possible way to the goal; otherwise animals and plants would not show so complete a correspondence in this respect in the higher stages of their evolution" ('09, p. 116). How such linear aggregates can have arisen is not easy for us to picture. A rough analogy may perhaps be offered by the familiar linear aggregates of Protista and other simple organisms, though such aggregates do not divide by longitudinal fission.

It would be unprofitable to speculate concerning how the chromioles came to assume their fixed serial order in each species; how the linear aggregates (chromosomes) became fixed in number; how they learned to conjugate during synapsis with due regard to law and order, to make definite exchanges of material, and to separate in orderly fashion. Merely to state such problems is to force a confession of abysmal ignorance. We may, however, venture the surmise that in some degree the primitive linear aggregates or chromosomes were from the first in some measure qualitatively different, and that their differences grew with the evolution of the nucleus; but even in their most highly differentiated condition, it seems probable that the chromosomes in any given species still consist largely of the same materials, and that their differences affect only certain components.[1]

Somewhat more accessible is the second main historical problem of mitosis, namely, the origin and evolution of the achromatic figure; and here we are brought to the hypothesis of binuclearity in another form.[2]

Its starting point was the assumption of Hertwig that primitively the cell contained two nuclei of which one has retained its "chromatin" to form the ordinary nucleus of the metazoan cell, while the other has lost its chromatin and become converted into a division-center. Bütschli and Heidenhain suggested that this differentiation is foreshadowed in the cil-

[1] *Cf.* Wilson ('12, '14).

[2] See Bütschli ('91), R. Hertwig ('92), Heidenhain ('94), Lauterborn ('95, '96), Schaudinn ('96, 05), and Hartmann and Prowazek ('07).

iates by the presence of the macronucleus and micronucleus, the former representing the trophic, the latter the kinetic nucleus and the incipient central body. This view is manifestly improbable, for all available evidence indicates the highly specialized nature of the ciliates as a group. Lauterborn, on the other hand, assumed the starting point to have been a cell containing two equal and similar nuclei, as is the case, for instance, in *Amœba diploidea* (Fig. 296). The intra-nuclear division-center so common in Protozoa was thus left unexplained.

The hypothesis underwent a further development with Schaudinn's discovery ('05) of the parabasal body in the trypanosomes, which he called the "blepharoplast" and considered as the derivative of a second nucleus. The trypanosome was thus considered, like the ciliates, as binucleate, containing a larger vegetative or trophic nucleus and a smaller kinetic nucleus (the "blepharoplast"), concerned especially with the production of the flagellum, near the base of which it lies.[1] Both "nuclei" were believed to contain "chromatin" and to divide mitotically; but later observers have found no evidence of either conclusion in case of the "blepharoplast" (parabasal body).[2]

Meanwhile Schaudinn's conception was further elaborated by Hartmann and Prowazek (*op. cit.*) by the assumption that the "kinetonucleus" or "blepharoplast" of the trypanosomes is represented in many Protista by the "endosome" or "karyosome," the nucleus being in such cases (as was hinted by Schaudinn in 1896) an "amphikaryon" in which a kinetic nucleus is included within a trophic and often in its turn includes a central granule or centriole. These authors cite many cases in which the karyosome plays the part of an intra-nuclear division-center (*e. g.*, the "nucleolocentrosome" of *Euglena*, p. 206) and others in which the division of the karyosome is said to be initiated by division of a centriole within it—*e. g.*, in *Amœba froschi* or in the genus *Entamœba*. By loss of its chromatin the karyosome becomes a true intranuclear "centrosome," which may escape from the nucleus (as in the budding of *Acanthocystis*, Fig. 325) to form an extra-nuclear body that may persist as such through many divisions. It was thus sought on the one hand to reconcile the binuclearity hypothesis with the views of R. Hertwig ('98), and of Boveri ('00), who assumed the division-

[1] By Laveran and Mesnil ('02), followed by French writers generally, the kinetic nucleus was called a "centrosome." Schaudinn's term blepharoplast was previously applied by Senn ('00) to the basal granule of the flagellum in flagellates, still earlier by Webber ('97) to the cilia-forming body in cycads; and in this usage he was followed by German writers generally. Woodcock's term "kinetonucleus" for this structure was adopted by Minchin, Dobell and other English writers, who reserved the name "blepharoplast" for the basal granule alone, and considered it to be homologous with a "centrosome." Its designation as the "parabasal body," has earlier been indicated (p. 694).

[2] See for instance Novy and McNeal ('05), E. and E. Sergent ('05, '07), Woodcock ('10), Minchin and Woodcock ('11), Werbitzki ('10), etc.

center to have been originally differentiated as an intra-nuclear body in a single nucleus.

This much discussed assumption, in the words of one of its critics, strove to make a second nucleus appear in many Protozoa where to the unaided imagination but one such structure is actually present; [1] and it has failed to convince most investigators of its correctness or even of its convenience. It becomes at once untenable if we admit the identity of the parabasal body with the "blepharoplast" or "kinetonucleus" of the trypanosomes and other forms; for in many of the flagellates a typical karyosome is also present (Figs. 337, 338). That an intra-nuclear structure like the karyosome was the forerunner of the division-center of higher forms has been made very probable by many investigations upon Protista, heretofore considered (p. 204). To consider this body as a nucleus within a nucleus is, however, to allow the supposed exigencies of an hypothesis to close our eyes to plain facts; this was indeed admitted by Hartmann who, in a later work ('11) withdrew this portion of his conception though still adhering to it in more restricted form. To the writer it seems simpler and more plausible to consider the original condition as having been a uninucleated one with an intra-nuclear division-center, which may very well have been similar to the karyosome of many existing Protozoa.

If we turn finally to the nature and origin of the cell-components in their earliest forms we find ourselves reduced to purely speculative considerations. We have considered the possibility that the protoplasmic basis or hyaloplasm may contain numerous minute self-propagating dispersed bodies lying beyond the limits of microscopical vision and forming a possible source of many of the visible formed components of the cell. Accepting some such view, for the sake of argument, we might raise the question as to which came first, the corpuscles or the apparently homogeneous basis in which they are suspended? Did corpuscles arise as secondary differentiations of a "continuous" protoplasm, or was the latter (like the matrix of a zoögloea) a product of corpuscles originally capable of separate and independent existence? It seems legitimate to ask this question in view of the supposed existence to-day of living organisms of this order of magnitude in the form of the filterable pathogenic microörganisms, of which nearly 40 species are said to be known.[2] Some of these still lie above the limits of microscopical vision, *e. g.*, the germ of poliomyelitis in man and of pleuropneumonia in cattle; [3] others are invisible, or as yet have not been seen. The experiments of Esmarch ('02) and others suggest that this may in some cases be due to the extreme tenuity of elongated forms, such as spirochætes; but it is at least possible that forms exist whose linear dimensions lie

[1] Swezey ('16), p. 180. [2] Lipschütz ('13). [3] *Cf.* Jordan, p. 510.

below the present range of visibility. The organisms here in question are parasitic (pathogenic); but it is also possible, as Minchin has especially urged, that many non-parasitic organisms of equal minuteness may now exist unknown to us, since we have no means of perceiving their effects.[1]

Such an hypothesis is of course unverifiable, and for this reason will to many appear worthless. As a purely speculative construction, however, it seems to the writer to offer possibilities concerning the early evolution of the cell that are worth considering, even though it brings us no nearer to a conception of the origin of life or a comprehension of organic individuality. This view was implied in Altmann's original development of his granulum-theory (p. 720) and has been developed by various later writers.[2] By Minchin the earliest living organisms were conjectured to have been minute, possibly ultra-microscopic particles to which he applies Mereschkowsky's term *biococci;* and which were assumed to be composed of "chromatin," the cytoplasm of higher forms being considered a secondary product, constituting a "ground-substance" in which the biococci were suspended in the form of chromidial granules ('15, p. 19). On the other hand, Mereschkowsky ('10), in an entertaining fantasy, has developed the hypothesis that the dualism of the cell in respect to nuclear and cytoplasmic substance resulted from a symbiotic association of two types of primordial microorganisms, that were originally distinct, one including primitive non-nucleated Monera composed of "amœboplasm," the other ultra-microscopical bacteria-like "biococci." By ingestion of the latter by the Monera arose a symbiotic association of the two forms, the cocci becoming chromidial granules and thus ultimately forming the nucleus. In further flights of the imagination Mereschkowsky suggests the origin of the whole group of fungi from bacteria independently of other plants, and of the green plants by a symbiotic union of between colorless nucleated cells and minute Cyanophyceæ, the latter giving rise to the chloroplasts. The latter speculation cannot be considered as totally baseless in view of the symbiotic association of unicellular green algæ with fungi in the lichens, the presence of chlorophyll-bearing bodies in many Protozoa and lower Metazoa (*e. g.*, in *Hydra*) which still form a subject of discussion, *i. e.*, as to whether they are likewise symbiotic algæ or products of the animal itself, with the evidence on the whole favoring the former alternative.[3] Even so cautious an observer as Pfeffer once considered the possibility that the cell may have been the product of a symbiosis between nucleus and cytosome, while Boveri

[1] *Cf.* Miehe ('23). This observer's attempts to determine (by the method of "ultrafiltration") whether ultramicroscopical organisms are of widespread occurrence in nature were negative.

[2] See especially Mereschkowsky ('10), Minchin ('15), Bridges ('22).

[3] Fulton ('22), etc.

suggested a "symbiosis of two kinds of simple plasma-structures—Monera, if we may so call them—in such fashion that a number of smaller forms, the chromosomes, established themselves within a larger one which we now call the cytosome." [1] More recently Wallin ('22) has maintained that chondriosomes may be regarded as symbiotic bacteria whose association with the other cytoplasmic components may have arisen in the earliest stages of evolution (p. 712). To many, no doubt, such speculations may appear too fantastic for present mention in polite biological society; nevertheless it is within the range of possibility that they may some day call for more serious consideration.

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