

CHAPTER II

CELL-DIVISION

“Wo eine Zelle entsteht, da muss eine Zelle vorausgegangen sein, ebenso wie das Thier nur aus dem Thiere, die Pflanze nur aus der Pflanze entstehen kann. Auf diese Weise ist, wengleich es einzelne Punkte im Körper gibt, wo der strenge Nachweis noch nicht geliefert ist, doch das Princip gesichert, dass in der ganzen Reihe alles Lebendigen, dies mögen nun ganze Pflanzen oder thierische Organismen oder integrirende Theile derselben sein, ein ewiges Gesetz der *continuirtlichen Entwicklung* besteht.”
VIRCHOW.¹

THE law of genetic cellular continuity, first clearly stated by Virchow in the above words, has now become one of the primary data of biology, and the advance of research is ever adding weight to the conclusion that the cell has no other mode of origin than by division of a preëxisting cell. In the multicellular organism all the tissue-cells arise by continued division from the original germ-cell, and this in its turn arises by the division of a cell preëxisting in the parent-body. By *cell-division*, accordingly, the hereditary substance is split off from the parent-body; and by cell-division, again, this substance is handed on by the fertilized egg-cell or oöperm to every part of the body arising from it.² Cell-division is, therefore, one of the central facts of development and inheritance.

The first two decades after Schleiden and Schwann ('40-'60) were occupied with researches, on the part both of botanists and of zoölogists, which finally demonstrated the universality of this process and showed the authors of the cell-theory to have been in error in asserting the independent origin of cells out of a formative blastema.³ The mechanism of cell-division was not precisely investigated until long afterward, but the researches of Remak ('41), Kölliker ('44), and others showed that an essential part of the process is a division of both the nucleus and the cell-body. In 1855 (*l.c.*, pp. 174, 175), and again in 1858, Remak gave as the general result of his researches the following synopsis or scheme of cell-division. Cell-division, he asserted, proceeds from the centre toward the periphery. It begins with the division of the nucleolus, is continued by simple constriction and division of the nucleus, and is completed by division of the cell-

¹ *Cellularpathologie*, p. 25, 1858.

² Cf. Introduction, p. 10.

³ For a full historical account of this period, see Remak, *Untersuchungen über die Entwicklung der Wirbelthiere*, 1855, pp. 164-180. Also Tyson on the *Cell-doctrine* and Sachs's *Geschichte der Botanik*.

body and membrane (Fig. 24). For many years this account was accepted, and no essential advance beyond Remak's scheme was made for nearly twenty years. A number of isolated observations were, however, from time to time made, even at a very early period, which seemed to show that cell-division was by no means so simple an operation as Remak believed. In some cases the nucleus seemed to disappear entirely before cell-division (the germinal vesicle of the ovum, according to Reichert, Von Baer, Robin, etc.); in others to become lobed or star-shaped, as described by Virchow and by Remak himself (Fig. 24, *f*). It was not until 1873 that the way was opened for a better understanding of the matter. In this year the discoveries of Anton Schneider, quickly followed by others in the same direction by Bütschli, Fol, Strasburger, Van Beneden, Flemming, and Hertwig, showed cell-division to be a far more elaborate process than had been

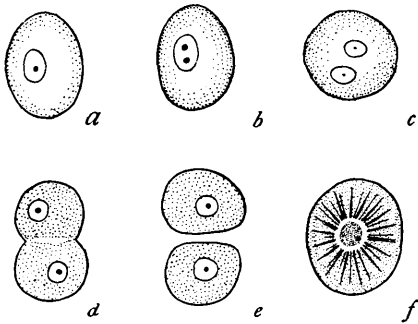


Fig. 24.— Direct division of blood-cells in the embryo chick, illustrating Remak's scheme. [REMAK.]

a-e. Successive stages of division; *f.* cell dividing by mitosis.

supposed, and to involve a complicated transformation of the nucleus to which Schleicher ('78) afterward gave the name of *karyokinesis*. It soon appeared, however, that this mode of division was not of universal occurrence; and that cell-division is of two widely different types, which Van Beneden ('76) distinguished as *fragmentation*, corresponding nearly to the simple process described by Remak, and *division*, involving the more complicated process of karyokinesis. Three years

later Flemming ('79) proposed to substitute for these the terms *direct* and *indirect* division, which are still used. Still later ('82) the same author suggested the terms *mitosis* (indirect or karyokinetic division) and *amitosis* (direct or akinetic division), which have rapidly made their way into general use, though the earlier terms are often employed.

Modern research has demonstrated the fact that amitosis or direct division, regarded by Remak and his immediate followers as of universal occurrence, is in reality a rare and exceptional process; and there is reason to believe, furthermore, that it is especially characteristic of highly specialized cells incapable of long-continued multiplication or such as are in the early stages of degeneration, for instance, in glandular epithelia and in the cells of transitory embryonic envelopes, where it is of frequent occurrence. Whether this

view be well founded or not, it is certain that in all the higher and in many of the lower forms of life, indirect division or mitosis is the typical mode of cell-division. It is by mitotic division that the germ-cells arise and are prepared for their union during the process of maturation, and by the same process the oöperm segments and gives rise to the tissue-cells. It occurs not only in the highest forms of plants and animals, but also in such simple forms as the rhizopods, flagellates, and diatoms. We may, therefore, justly regard it as the most general expression of the "eternal law of continuous development" on which Virchow insisted.

A. OUTLINE OF INDIRECT DIVISION OR MITOSIS (KARYOKINESIS)

In the present state of knowledge it is somewhat difficult to give a connected general account of mitosis, owing to the uncertainty that hangs over the nature and functions of the centrosome. For the purpose of the following preliminary outline, we shall take as a type mitosis in which a distinct and persistent centrosome is present, as has been most clearly determined in the maturation and cleavage of various animal eggs, and in the division of the testis-cells. In such cases the process involves three parallel series of changes, which affect the nucleus, the centrosome, and the cytoplasm of the cell-body respectively. For descriptive purposes it may conveniently be divided into a series of successive stages or phases, which, however, graduate into one another and are separated by no well-defined limits. These are: (1) The *Prophases*, or preparatory changes; (2) the *Metaphase*, which involves the most essential step in the division of the nucleus; (3) the *Anaphases*, in which the nuclear material is distributed; (4) the *Telophases*, in which the entire cell divides and the daughter-cells are formed.

1. *Prophases*. — (a) *The Nucleus*. As the cell prepares for division, the most conspicuous fact is a transformation of the nuclear substance, involving both physical and chemical changes. The chromatin-substance rapidly increases in staining-power, loses its net-like arrangement, and finally gives rise to a definite number of separate intensely staining bodies, usually rod-shaped, known as *chromosomes*. As a rule this process, exemplified by the dividing cells of the salamander-epidermis (Fig. 1) or those of plant-meristem (Fig. 2), takes place as follows. The chromatin resolves itself little by little into a more or less convoluted thread, known as the *skrein* (Knäuel) or *spireme*, and its substance stains far more intensely than that of the reticulum (Fig. 25). The spireme-thread is at first fine and closely convoluted, forming the "close spireme." Later the thread thickens and shortens and the

convolution becomes more open ("open spireme"). In some cases there is but a single continuous thread; in others, the thread is from

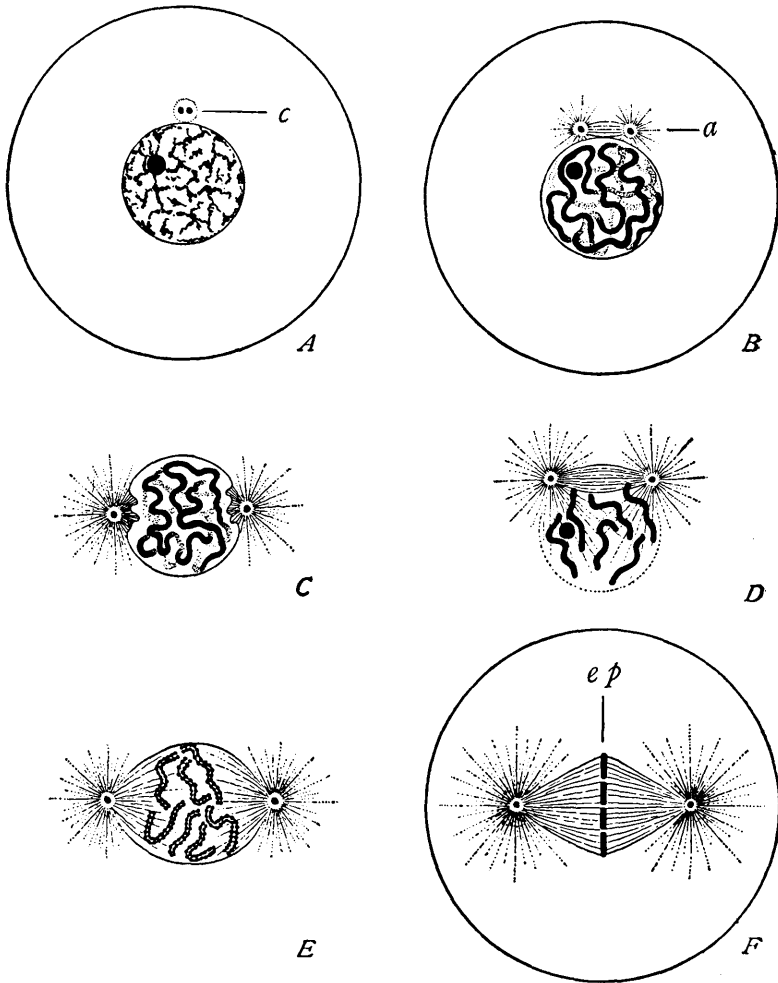


Fig. 25. — Diagrams showing the prophases of mitosis.

A. Resting cell with reticular nucleus and true nucleolus; at *c* the attraction-sphere containing two centrosomes. *B.* Early prophase; the chromatin forming a continuous *spireme*, nucleolus still present; above, the amphiaster (*a*). *C. D.* Two different types of later prophases. *C.* Disappearance of the primary spindle, divergence of the centrosomes to opposite poles of the nucleus (examples, some plant-cells, cleavage-stages of many eggs). *D.* Persistence of the primary spindle (to form in some cases the "central spindle"), fading of the nuclear membrane, ingrowth of the astral rays, segmentation of the spireme-thread to form the chromosomes (examples, epidermal cells of salamander, formation of the polar bodies). *E.* Later prophase of type *C*; fading of the nuclear membrane at the poles, formation of a new spindle inside the nucleus; precocious splitting of the chromosomes (the latter not characteristic of this type alone). *F.* The mitotic figure established; *ep*, the equatorial plate of chromosomes. (Cf. Figs. 21, 27, 32, etc.)

its first appearance divided into a number of separate pieces or segments, forming a *segmented spireme*. In either case it ultimately breaks transversely to form the *chromosomes*, which in most cases have the form of rods, straight or curved, though they are sometimes spherical or ovoidal, and in certain cases may be joined together in the form of rings. The staining-power of the chromatin is now at a maximum. As a rule the nuclear membrane meanwhile fades away and finally disappears, though there are some cases in which it persists more or less completely through all the phases of division. The chromosomes now lie naked in the cell, and the ground-substance of the nucleus becomes continuous with the surrounding cytoplasm (Fig. 25, *D, E, F*).¹

The remarkable fact has now been established with high probability that *every species of plant or animal has a fixed and characteristic number of chromosomes, which regularly recurs in the division of all of its cells; and in all forms arising by sexual reproduction the number is even*. Thus, in some of the sharks the number is 36; in certain gastropods it is 32; in the mouse, the salamander, the trout, the lily, 24; in the worm *Sagitta*, 18; in the ox, guinea-pig, and in man² the number is said to be 16, and the same number is characteristic of the onion. In the grasshopper it is 12; in the hepatic *Pallavicinia* and some of the nematodes, 8; and in *Ascaris*, another thread-worm, 4 or 2. In the crustacean *Artemia* it is 168.³ Under certain conditions, it is true, the number of chromosomes may be less than the normal in a given species; but these variations are only apparent exceptions (p. 87). The even number of chromosomes is a most interesting fact, which, as will appear hereafter (p. 205), is due to the derivation of one-half the number from each of the parents.

The nucleoli differ in their behaviour in different cases. Net-knots, or chromatin-nucleoli, contribute to the formation of the chromosomes; and in cases such as *Spirogyra* (Meunier, '86, and Moll, '93) or *Actinosphaerium* (R. Hertwig, '99), where the whole of the chromatin is at one period concentrated into a single mass, the whole chromatic figure thus appears to arise from a "nucleolus." True nucleoli or plasmosomes sooner or later disappear; and the greater number of observers agree that they do not take part in the chromosome-formation. In a considerable number of forms (*e.g.* during the formation of the polar

¹ The spireme-formation is by no means an invariable occurrence in mitosis. In a considerable number of cases the chromatin-network resolves itself directly into the chromosomes, the chromatic substance becoming concentrated in separate masses which never form a continuous thread. Such cases are connected by various gradations with the "segmented spireme."

² Flemming believes the number in man to be considerably greater than 16.

³ For a more complete list see p. 206.

bodies in various eggs) the nucleolus is cast out into the cytoplasm as the spindle forms, to persist as a "metanucleus" for some time before its final disappearance (Fig. 104). More commonly the nucleolus fades away *in situ*, sometimes breaking into fragments meanwhile, while the chromosomes and spindle are forming. The fate of the material is in this case only conjectural. An interesting view is that of Strasburger ('95, '97), who suggests that the true nucleoli are to be regarded as storehouses of "kinoplasmic" material, which is either directly used in the formation of the spindle, or, upon being cast out of the nucleus, adds to the cytoplasmic store of "kinoplasm" available for future mitosis.

(b) *The Amphiaster*. Meanwhile, more or less nearly parallel with these changes in the chromatin, a complicated structure known as the *amphiaster* (Fol, '77) makes its appearance in the position formerly occupied by the nucleus (Fig. 25, B-F). This structure consists of a fibrous spindle-shaped body, the *spindle*, at either pole of which is a star or *aster* formed of rays or astral fibres radiating into the surrounding cytoplasm, the whole strongly suggesting the arrangement of iron filings in the field of a horseshoe magnet. The centre of each aster is occupied by a minute body, known as the *centrosome* (Boveri, '88), which may be surrounded by a spherical mass known as the *centrosphere* (Strasburger, '93). As the amphiaster forms, the chromosomes group themselves in a plane passing through the equator of the spindle, and thus form what is known as the *equatorial plate*.

The amphiaster arises under the influence of the centrosome of the resting cell, which divides into two similar halves, an aster being developed around each while a spindle stretches between them (Figs. 25, 27). In most cases this process begins outside the nucleus, but the subsequent phenomena vary considerably in different forms. In some forms (tissue-cells of the salamander) the amphiaster at first lies tangentially outside the nucleus, and as the nuclear membrane fades away, some of the astral rays grow into the nucleus from the side, become attached to the chromosomes, and finally pull them into position around the equator of the spindle, which is here called the *central spindle* (Figs. 25, D, F; 27). In other cases the original spindle disappears, and the two asters pass to opposite poles of the nucleus (some plant mitoses and in many animal-cells). A spindle is now formed from rays that grow into the nucleus from each aster, the nuclear membrane fading away at the poles, though in some cases it may be pushed in by the spindle-fibres for some distance before its disappearance (Figs. 25, 32). In this case there is apparently no central spindle. In a few exceptional cases, finally, the amphiaster may arise inside the nucleus (p. 304).

The entire structure, resulting from the foregoing changes, is

known as the *karyokinetic* or *mitotic figure*. It may be described as consisting of two distinct parts; namely, 1, the *chromatic figure*, formed by the deeply staining chromosomes; and, 2, the *achromatic figure*, consisting of the spindle and asters which, in general, stain but slightly. The fibrous substance of the achromatic figure is gener-

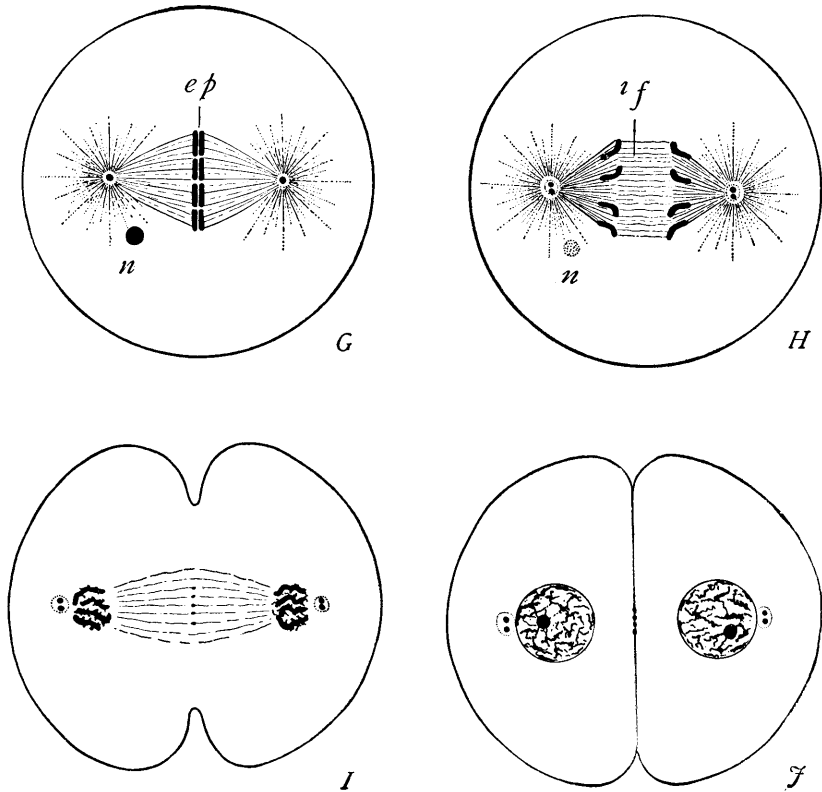


Fig. 26. — Diagrams of the later phases of mitosis.

G. Metaphase; splitting of the chromosomes (*e.p.*). *n.* The cast-off nucleolus. H. Anaphase; the daughter-chromosomes diverging, between them the interzonal-fibres (*i.f.*), or central spindle; centrosomes already doubled in anticipation of the ensuing division. I. Late anaphase or telophase, showing division of the cell-body, mid-body at the equator of the spindle and beginning reconstruction of the daughter-nuclei. J. Division completed.

ally known as *archoplasm* (Boveri, '88), but this term is not applied to the centrosome within the aster.

2. *Metaphase*. — The *prophases* of mitosis are, on the whole, preparatory in character. The *metaphase*, which follows, forms the initial phase of actual division. Each chromosome splits lengthwise into two exactly similar halves, which afterward diverge to opposite poles of the spindle, and here each group of daughter-chromosomes

finally gives rise to a daughter-nucleus (Fig. 26). In some cases the splitting of the chromosomes cannot be seen until they have grouped themselves in the equatorial plane of the spindle; and it is only in this case that the term "metaphase" can be applied to the mitotic figure as a whole. In a large number of cases, however, the splitting may take place at an earlier period in the spireme-stage, or even, in a few cases, in the reticulum of the mother-nucleus (Figs. 54, 55). Such variations do not, however, affect the essential fact that *the chromatic network is converted into a thread*¹ *which, whether continuous or discontinuous, splits throughout its entire length into two exactly equivalent halves.* The splitting of the chromosomes, discovered by Flemming in 1880, is the most significant and fundamental operation of cell-division; for by it, as Roux first pointed out ('83), the entire substance of the chromatic network is precisely halved, and *the daughter-nuclei receive precisely equivalent portions of chromatin from the mother-nucleus.* It is very important to observe that the *nuclear* division always shows this exact quality, whether division of the cell-body be equal or unequal. The minute polar body, for example (p. 238), receives exactly the same amount of chromatin as the egg, though the latter is of gigantic size as compared with the former. On the other hand, the size of the asters varies with that of the daughter-cells (Figs. 58, 175), though not in strict ratio. The fact is one of great significance for the general theory of mitosis, as will appear beyond.

3. *Anaphases.* — After splitting of the chromosomes, the daughter-chromosomes, arranged in two corresponding groups,² diverge to opposite poles of the spindle, where they become closely crowded in a mass near the centre of the aster. As they diverge, the two groups of daughter-chromosomes are connected by a bundle of achromatic fibres, stretching across the interval between them, and known as the *interzonal fibres* or *connecting fibres*.³ In some cases these differ in a marked degree from the other spindle-fibres; and they are believed by many observers to have an entirely different origin and function. A view now widely held is that of Hermann, who regards these fibres as belonging to a *central spindle*, surrounded by a peripheral layer of *mantle-fibres* to which the chromosomes are attached, and only exposed to view as the chromosomes separate.⁴ Almost invariably in the division of plant-cells and often in that of animal cells these

¹ It was this fact that led Flemming to employ the word *mitosis* (*μτρος*, a thread).

² This stage is termed by Flemming the *dyaster*, a term which should, however, be abandoned in order to avoid confusion with the earlier word *amphiaster*. The latter convenient and appropriate term clearly has priority.

³ *Verbindungsfasern* of German authors; *filaments réunissants* of Van Beneden.

⁴ Cf. p. 105.

fibres show during this period a series of deeply staining thickenings in the equatorial plane forming the *cell-plate* or *mid-body*. In plant-mitoses this is a very conspicuous structure (Fig. 34). In animal cells the mid-body is usually less developed and sometimes rudimentary, being represented by only a few granules or even a single one (Fig. 29). Its later history is described below.

4. *Telophases*.—In the final phases of mitosis, the entire cell divides in two in a plane passing through the equator of the spindle, each of the daughter-cells receiving a group of chromosomes, half of the spindle, and one of the asters with its centrosome. Meanwhile, a daughter-nucleus is reconstructed in each cell from the group of chromosomes it contains. The nature of this process differs greatly in different kinds of cells. Sometimes, as in the epithelial cells of Amphibia, especially studied by Flemming and Rabl, and in many plant-cells, the daughter-chromosomes become thickened, contorted, and closely crowded to form a *daughter-spireme*, closely similar to that of the mother-nucleus (Fig. 29); this becomes surrounded by a membrane, the threads give forth branches, and thus produce a reticular nucleus. A somewhat similar set of changes takes place in the segmenting eggs of *Ascaris* (Van Beneden, Boveri). In other cases, as in many segmenting ova, each chromosome gives rise to a hollow vesicle, after which the vesicles fuse together to produce a single nucleus (Fig. 52). When first formed, the daughter-nuclei are of equal size. If, however, division of the cell-body has been unequal, the nuclei become, in the end, correspondingly unequal—a fact which, as Conklin and others have pointed out, proves that the size of the nucleus is controlled by that of the cytoplasmic mass in which it lies.

The fate of the achromatic structures varies considerably, and has been accurately determined in only a few cases. As a rule, the spindle-fibres disappear more or less completely, but a portion of their substance sometimes persists in a modified form (*e.g.* the *Nebenkern*, p. 163). In dividing plant-cells, the cell-plate finally extends across the entire cell and splits into two layers, between which appears the membrane by which the daughter-cells are cut apart.¹ A nearly similar process occurs in a few animal cells,² but as a rule the cell-plate is here greatly reduced and forms no membrane, the cell dividing by constriction through the equatorial plane. Even in this case, however, the division-plane is often indicated before division takes place by a peculiar modification of the cytoplasm in the equatorial plane outside the spindle (Fig. 30). This region is sometimes called the *cytoplasmic plate*, in contradistinction to the *spindle-plate*, or mid-body proper. In the prophases and meta-

¹ Cf. Strasburger, '98.

² Cf. Hoffmann, '98.

phases the astral rays often cross one another in the equatorial region outside the spindle. During the anaphases, however, this crossing disappears, the rays from the two asters now meeting at an angle along the cytoplasmic plate (Fig. 31). Constriction and division of the cell then occur.¹

The aster may in some cases entirely disappear, together with the centrosome (as occurs in the mature egg). In a large number of cases, however, the centrosome persists, lying either outside or more rarely inside the nucleus and dividing into two at a very early period. This division is clearly a precocious preparation for the ensuing division of the daughter-cell, and it is a remarkable fact that it occurs as a rule during the early anaphase, before the mother-cell itself has divided. There are apparently, however, some cases in which the centrosome remains undivided during the resting stage and only divides as the process of mitosis begins.

Like the centrosome, the aster or its central portion may persist in a more or less modified form throughout the resting state of the cell, forming a structure generally known as the *attraction-sphere*. This body often shows a true astral structure with radiating fibres (Figs. 8, 49); but it is sometimes reduced to a regular spherical mass which may represent only a portion of the original aster (Fig. 7).

B. ORIGIN OF THE MITOTIC FIGURE

The nature and source of the material from which the mitotic figure arises form a problem that has been almost continuously under discussion since the first discovery of mitosis, and is even now but partially solved. The discussion relates, however, almost solely to the achromatic figure (centrosome, spindle, and asters); for every one is agreed that the chromatic figure (chromosomes) is directly derived from the chromatin-network, as described above, so that there is no breach in the continuity of the chromatin from one cell-generation to another. With the achromatic figure the case is widely different. The material of the spindle and asters must be derived from the nucleus, from the cytoplasm, or from both; and most of the earlier research was devoted to an endeavour to decide between these possibilities. The earliest observers ('73-'75) supposed the achromatic figure to disappear entirely at the close of cell-division, and most of them (Bütschli, Strasburger, Van Beneden, '75) believed it to be re-formed at each succeeding division out of the nuclear substance. The entire mitotic figure was thus conceived as a metamorphosed nucleus. Later researches ('75-'85) gave contradic-

¹ See p. 318. Cf. Kostanecki, '97, and Hoffmann, '98.

tory and apparently irreconcilable results. Fol ('79) derived the spindle from the nuclear material, the asters from the cytoplasm. Strasburger ('80) asserted that the entire achromatic figure arose

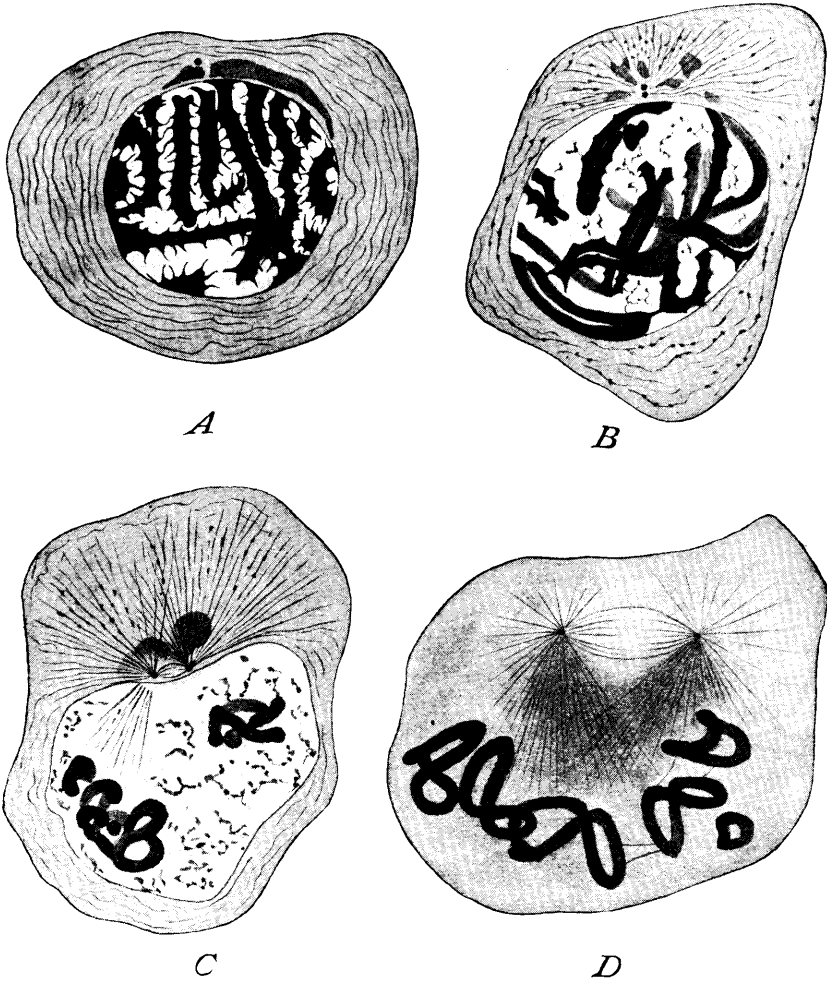


Fig. 27.—The prophases of mitosis (heterotypical form) in primary spermatocytes of *Salamandra*. [MEVES.]

A. Early segmented spireme; two centrosomes outside the nucleus in the remains of the attraction-sphere. *B.* Longitudinal splitting of the spireme, appearance of the astral rays, disintegration of the sphere. *C.* Early amphiaster and central spindle. *D.* Chromosomes in the form of rings, nuclear membrane disappeared, amphiaster enlarging, mantle-fibres developing.

from the cytoplasm, and to that view, in a modified form, he still adheres. Flemming ('82), on the whole, inclined to the opinion that the achromatic figure arose inside the nucleus, yet expressed the

opinion that the question of nuclear or cytoplasmic origin was one of minor importance. A long series of later researches on both plants and animals has fully sustained this opinion, showing that the origin of the achromatic figure does in fact differ in different cases. Thus in Infusoria the entire mitotic figure is of intranuclear origin (there are, however, no asters); in echinoderm eggs the spindle is of nuclear, the asters of cytoplasmic, origin; in the testis-cells and some tissue-cells of the salamander, a complete amphiaster is first formed in the cytoplasm, but to this are afterward added elements probably derived from the linin-network; while in higher plants there is some reason to believe that the entire achromatic figure may be of cytoplasmic origin. Such differences need not surprise us when we reflect that the achromatic part of the nucleus (linin-network, etc.) is probably of the same general nature as the cytoplasm.¹

Many observers have maintained that the material of the astral rays and spindle-fibres is directly derived from the substance of the protoplasmic meshwork, whether nuclear, cytoplasmic, or both; but its precise origin has long been a subject of debate. This question, critically considered in Chapter VI., will be here only briefly sketched. By Klein ('78), Van Beneden ('83), Carnoy ('84, '85), and a large number of later observers, the achromatic fibres, both of spindles and of asters, are regarded as identical with those of a preëxisting reticulum which have merely assumed a radiating arrangement about the centrosome. The amphiaster has, therefore, no independent existence, but is merely an image, as it were, somewhat like the bipolar figure arising when iron filings are strewn in the field of a horseshoe magnet. Boveri, on the other hand, who has a small but increasing following, maintains that the amphiasstral fibres are not identical with those of the preëxisting meshwork, but a new formation which, as it were, "crystallizes anew" out of the general protoplasmic substance. The amphiaster is therefore a new and independent structure, arising in, or indirectly from, the preëxisting material, but not by a *direct* morphological transformation of that material. This view, which has been advocated by Drüner ('94), Braus ('95), Meves ('97, 4, '98), and with which my own later observations ('99) also agree, is more fully discussed at page 318.

In 1887 an important forward step was taken through the independent discovery by Van Beneden and Boveri that in the egg of *Ascaris* the centrosome does not disappear at the close of mitosis, but remains as a distinct cell-organ lying beside the nucleus in the cyto-

¹ In the case of echinoderm eggs, I have found reason ('95, 2) for the conclusion that the spindle-fibres are derived not merely from the linin-substance, but also from the chromatin. Despite some adverse criticism, I have found no reason to change my opinion on this point. The possible significance of such a derivation is indicated elsewhere (p. 302).

plasm. These investigators agreed that the amphiaster is formed under the influence of the centrosome, which by its division creates two new "centres of attraction" about which the astral systems arise, and which form the foci of the entire dividing system. In them are centred the fibrillæ of the astral system, toward them the daughter-

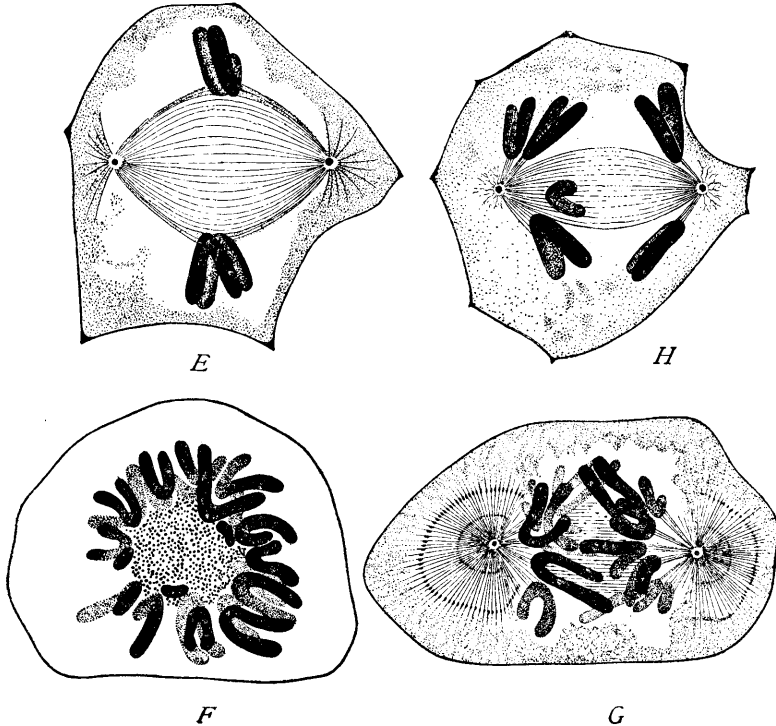


Fig. 28.—Metaphase and anaphases of mitosis in cells (spermatocytes) of the salamander. [DRÜNER.]

E. Metaphase. The continuous central spindle-fibres pass from pole to pole of the spindle. Outside them the thin layer of contractile mantle-fibres attached to the divided chromosomes, of which only two are shown. Centrosomes and asters. *F.* Transverse section through the mitotic figure showing the ring of chromosomes surrounding the central spindle, the cut fibres of the latter appearing as dots. *G.* Anaphase; divergence of the daughter-chromosomes, exposing the central spindle as the interzonal fibres; contractile fibres (principal cones of Van Beneden) clearly shown. *H.* Later anaphase (dyaster of Flemming); the central spindle fully exposed to view; mantle-fibres attached to the chromosomes. Immediately afterward the cell divides (see Fig. 29).

chromosomes proceed, and within their respective spheres of influence are formed the resulting daughter-cells. Both Van Beneden and Boveri fully recognized the importance of their discovery. "We are justified," said Van Beneden, "in regarding the attraction-sphere with its central corpuscle as forming a permanent organ, not only of the early blastomeres, but of all cells, and as constituting a cell-organ equal

in rank to the nucleus itself; and we may conclude that every central corpuscle is derived from a preëxisting corpuscle, every attraction-sphere from a preëxisting sphere, and that division of the sphere precedes that of the cell-nucleus."¹ Boveri expressed himself in similar terms regarding the centrosome in the same year ('87, 2, p. 153), and the same general result was reached by Vejdovsky nearly at the same time,² though it was less clearly formulated than by either Boveri or Van Beneden.

All these observers agreed, therefore, that the achromatic figure arose outside the nucleus, in the cytoplasm; that the primary impulse to cell-division was given, not by the nucleus, but by the centrosome, and that a new cell-organ had been discovered whose special office

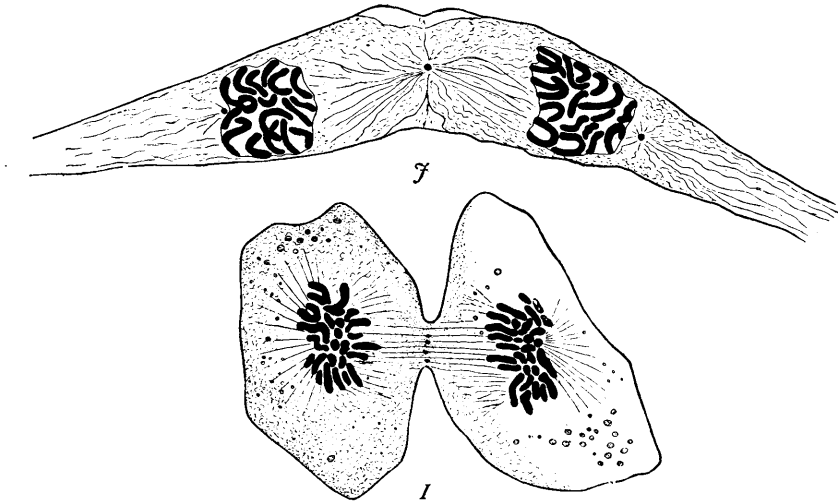


Fig. 20. — Final phases (telephases) of mitosis in salamander cells. [FLEMMING.]

I. Epithelial cell from the lung; chromosomes at the poles of the spindle, the cell-body dividing; granules of the "mid-body" or *Zwischenkörper* at the equator of the disappearing spindle. f. Connective tissue-cell (lung) immediately after division; daughter-nuclei reforming, the centrosome just outside of each; mid-body a single granule in the middle of the remains of the spindle.

was to preside over cell-division. "The centrosome is an independent permanent cell-organ, which, exactly like the chromatic elements, is transmitted by division to the daughter-cells. *The centrosome represents the dynamic centre of cell.*"³

That the centrosome does in many cases, especially in embryonic cells, behave in the manner stated by Van Beneden and Boveri seems at present to admit of no doubt; and it has been shown to occur in

¹ '87, p. 279.

² '88, pp. 151, etc.

³ Boveri, '87, 2, p. 153.

many kinds of adult tissue-cells during their resting state; for example in pigment-cells, leucocytes, connective tissue-cells, epithelial and endothelial cells, in certain gland-cells and nerve-cells, in the cells of some plant-tissues, and in some of the unicellular plants and animals, such as the diatoms and flagellates and rhizopods. On the other hand, Van Beneden's conception of the attraction-sphere has proved untenable; for this structure has been clearly shown in some cases to disintegrate and disappear at the close or the beginning of mitosis¹ (Fig. 27).

Whether the centrosome theory can be maintained is still in doubt; but evidence against it has of late rapidly accumulated.

In the first place, it has been shown that the primary impulse to cell-division cannot be given by fission of the centrosome, for there are several accurately determined cases in which the chromatin-elements divide independently of the centrosome, and it is now generally agreed that the division of chromatin and centrosome are two parallel events, the nexus between which still remains undetermined.²

Secondly, an increasing number of observers assert the total disappearance of the centrosome at the close of mitosis; while some very convincing observations have been made favouring the view that centrosomes may be formed *de novo* without connection with preëxisting ones (pp. 213, 305).

Thirdly, a large number of recent observers (including Strasburger and many of his pupils) of mitosis in the flowering plants and pteridophytes agree that in these forms *no centrosome exists at any stage of mitosis*, the centre of the aster being occupied by a vague reticular mass, and the entire achromatic figure arising by the gradual grouping of fibrous cytoplasmic elements (kinoplasm or filar plasm) about the nuclear elements.³ If we can assume the correctness of these observations, the centrosome-theory must be greatly modified, and the origin of the amphiaster becomes a far more complex problem than it appeared under the hypothesis of Van Beneden and Boveri. That such is indeed the case is indicated by nothing more strongly than by Boveri's own remarkable recent experiments on cell-division (referred to at page 108).

C. DETAILS OF MITOSIS

Comparative study has shown that almost every detail of the processes described above is subject to variation in different forms of cells. Before considering some of these modifications it may be well to point out what we are at present justified in regarding as its essential

¹ Cf. p. 323.

² Cf. p. 108.

³ Cf. p. 82.

features. These are: (1) The formation of the chromatic and achromatic figures; (2) the longitudinal splitting of the chromosomes or spireme-thread; (3) the transportal of the chromatin-halves to the respective daughter-cells. Each of these three events is endlessly varied in detail; yet the essential phenomena are everywhere the same, with one important exception relating to the division of the chromosomes that occurs in the maturation of certain eggs and spermatozoa.¹ It may be stated further that the study of mitosis in some of the lower forms (Protozoa) gives reason to believe that the asters are of secondary importance as compared with the spindle, and that the formation of spireme and chromosomes is but tributary to the division of the smaller chromatin-masses of which they are made up.

1. *Varieties of the Mitotic Figure*

(a) *The Achromatic Figure.* The phenomena involved in the history of the achromatic figure are in general most clearly displayed in embryonic or rapidly dividing cells, especially in egg-cells (Figs. 31, 60), where the asters attain an enormous development, and the centrosomes are especially distinct. In adult tissue-cells the asters are relatively small and difficult of demonstration, the spindle large and distinct; and this is particularly striking in the cells of higher plants where the asters are but imperfectly developed. Plant-mitoses are characterized by the prominence of the cell-plate (Fig. 34), which is rudimentary or often wanting in animals, a fact correlated no doubt with the greater development of the cell-membrane in plants. With this again is correlated the fact that division of the cell-body in animal cells generally takes place by constriction in the equatorial plane of the spindle; while in plant-cells the cell is usually cut in two by a cell-wall developed in the substance of the protoplasm and derived in large part from the cell-plate.

In animal cells we may distinguish two general types in the formation of the amphiaser, which are, however, connected by intermediate gradations. In the first of these, typically illustrated by the division of epithelial and testis-cells in the salamander (Flemming, Hermann, Drüner, Meves), a complete amphiaser is first formed in the cytoplasm outside the nucleus, while the nuclear membrane is still intact. As the latter fades away and the chromosomes appear, some of the astral rays grow into the nuclear space and become attached to the chromosomes, which finally arrange themselves in a ring about the original spindle (Figs. 27, 28). In the completed amphiaser, therefore, we may distinguish the original *central spindle* (Hermann, '91) from the surrounding *mantle-fibres*, the latter being

¹ Cf. Chapter V.

attached to the chromosomes, and being, according to Hermann, the principal agents by which the daughter-chromosomes are dragged apart. The mantle-fibres thus form two hollow cones or half-spindles, separated at their bases by the chromosomes and completely surrounding the continuous fibres of the central spindle, which come into view as the "interzonal fibres" during the anaphases (Fig. 28).

There is still considerable uncertainty regarding the origin and relation of these two sets of fibres. It is now generally agreed with Van Beneden that the mantle-fibres are essentially a part of the asters, *i.e.* are simply those astral rays that come into connection with the chromosomes —

wholly cytoplasmic in origin (Hermann, Drüner, MacFarland), or in part cytoplasmic, in part differentiated from the linnetwork (Flemming, Meves). Drüner ('95), Braus ('95) (salamander), and MacFarland (*Pleurophyllidia*, '97) believe the central spindle to arise secondarily through the union of two opposing groups of astral rays in the area between the centrosomes. On the other hand, Hermann ('91), Flemming ('91), Heidenhain ('94), Kostanecki ('97), Van der Stricht ('98), and others believe the central spindle to exist from the first in

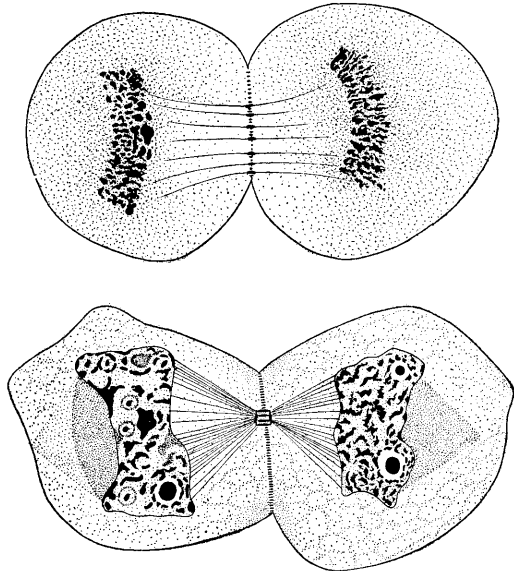


Fig. 30. — Mid-body in embryonic cells of *Limax*. [HOFFMANN.]

Earlier stage above, showing thickenings along the line of cleavage. Later stage, below, showing spindle-plate and cytoplasmic plate.

the form of fibres stretching between the diverging centrosomes; and Heidenhain believes them to be developed from a special substance, forming a "primary centrodesmus," which persists in the resting cell, and in which the centrosomes are embedded.¹ MacFarland's observations on gasteropod-eggs ('97) indicate that even nearly related forms may differ in the origin of the central spindle, since in *Pleurophyllidia* it is of secondary origin, as described above, while in *Diaulula* it is a primary structure developed from what he describes as the "centrosome," but which, as shown at page 314, is probably to be regarded as

¹ Cf. p. 315.

an attraction-sphere surrounding the centrosomes, and is perhaps comparable to Heidenhain's "centrodesmus."

In the second type, illustrated in the cleavage of echinoderm, annelid, molluscan, and some other eggs, a central spindle may be formed, — sometimes already during the anaphases of the preceding mitosis (Figs. 99, 155), — but afterward disappears, the asters moving

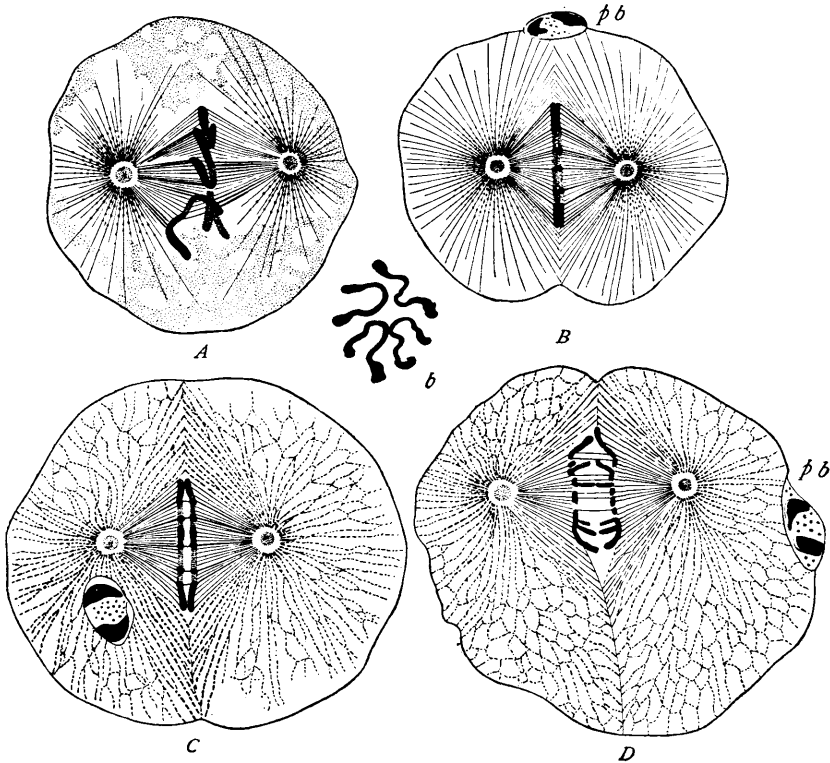


Fig. 31. — The middle phases of mitosis in the first cleavage of the *Ascaris*-egg. [BOVERI.]

A. Closing prophase, the equatorial plate forming. *B.* Metaphase; equatorial plate established and the chromosomes split; *b.* the equatorial plate, viewed *en face*, showing the four chromosomes. *C.* Early anaphase; divergence of the daughter-chromosomes (polar body at one side). *D.* Later anaphase; *p. b.* second polar body.

(For preceding stages see Fig. 90; for later stages Fig. 145.)

to opposite poles of the nucleus. Between these two poles a new spindle is then formed in the nuclear area, while astral rays grow out into the cytoplasm. There is strong evidence that in this case the entire spindle may arise inside the nucleus, *i.e.* from the substance of the linin-network, as occurs, for example, in the eggs of echinoderms (Fig. 25, *E*), and in the testis-cells of arthropods. In other cases, however, a part at least of the spindle is of cytoplasmic

origin, since the ends of the spindle begin to form before dissolution of the nuclear membrane, and the latter is pushed inwards in folds by the ingrowing fibres (Figs. 25, C, 99).¹ In some cases, however, it seems certain that the nuclear membrane fades away before completion of the spindle (first maturation-division of *Thalassema*, *Chaetopterus*), and it is probable that the middle region of the spindle is here formed from the linin-network. In most, if not all, mitoses of the second type the chromosomes do not form a ring about the equator of the spindle, but extend in a flat plate completely through

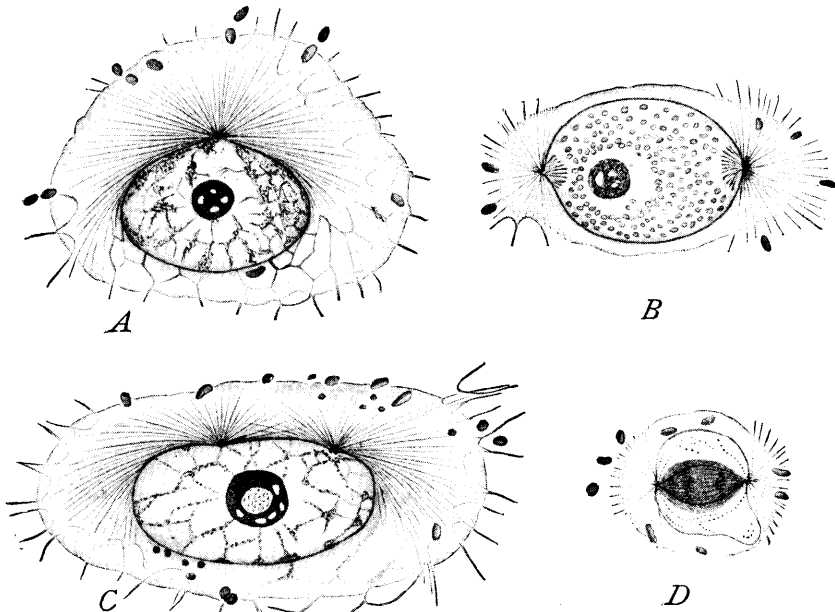


Fig. 32. — Mitosis in *Stypocaulon*. [SWINGLE.]

A. Early prophase with single aster and centrosome. B. Initial formation of intranuclear spindle. C. Divergence of the daughter-centrosomes. D. Early anaphase; nuclear membrane still intact.

its substance. Here, therefore, it is impossible to speak of a “central spindle.” It is nevertheless probable that the spindle-fibres are of two kinds, viz. continuous fibres, which form the interzonal fibres seen during the anaphases, and half-spindle fibres, extending only from the poles to the chromosomes. It is possible that these two kinds of fibres, though having the same origin, respectively corre-

¹ Cf. Platner ('86) on *Arion* and *Lepidoptera*, Watasé ('91) on *Loligo*, Braus ('95) on *Triton*, and Griffin ('96, '99) on *Thalassema*. Erlanger ('97, 5) endeavours to show that in the mitosis of embryonic cells in the cephalopods (*Septia*), where the inpushing of the membrane was previously shown by Watasé, the entire spindle arises from the nucleus.

spond in function to those of the central spindle and to the mantle-fibres. It seems probable that the difference between the two types of spindle-formation may be due to, or is correlated with, the fact that the nuclear transformation takes place relatively earlier in the first type. When the nucleus lags behind the spindle-formation the centrosomes take up their position prematurely, as it were, the central spindle disappearing to make way for the nucleus.

It is in the mitosis of plant-cells that the most remarkable type of achromatic figure has been observed. In some of the lower forms (Algæ) mitosis has been clearly shown to conform nearly to the process observed in animal cells, the amphiaster being provided with very large asters and distinct centrosomes, and its genesis corresponding broadly with the second type described above (Figs. 32, 33), though with some interesting modifications of detail.¹ Swingle ('97) describes in *Stytopocaulon* a process closely similar to that seen in many animal cells, the minute but very distinct centrosomes being surrounded by quite typical cytoplasmic asters, passing to opposite poles of the nucleus, and a spindle then developing between them out of the achromatic nuclear substance (Fig. 32). In the flowering plants and pteridophytes, on the other hand, mitosis seems to be of a quite different type, apparently taking place *in the entire absence of centrosomes*. Guignard ('91, 1, '92, 2) clearly described and figured typical centrosomes and attraction-spheres both in the ordinary mitosis (Fig. 34) and in the fertilization of the higher plants, giving an account of their behaviour nearly agreeing with the views then prevailing among zoologists. Although these accounts have been supported by some other workers,² and have recently been in part reiterated by Guignard himself ('98, 1), they have not been sustained by some of the best and most careful later observers, who describe a mode of spindle-formation differing radically from that seen in thal-
lophytes and in animals generally.³ According to these observations, begun by Farmer and Belajeff, and strongly sustained by the careful studies of Osterhout, Mottier, Nemeč, and others, the achromatic figure is almost wholly of cytoplasmic origin, arising from a fibrillar material ("kinoplasm" or "filar plasm," of Strasburger), which at the beginning of mitosis forms a net-like mass surrounding the nucleus, from which fibrillæ radiate out into the cytoplasm. As the nuclear membrane fades, these fibrillæ, continually increasing, invade the nuclear area, gather themselves into bundles, converging to a number

¹ See especially Swingle ('97) on *Sphacelariaceæ*, Strasburger ('97) on *Fucus*, Mottier ('98) on *Dictyota*; cf. also Harper ('97) on *Erysiphe* and *Peziza*.

² Cf. Schaffner ('98), Fulmer ('98).

³ See Osterhout ('97) on *Equisetum*, Mottier ('97, 1, '97, 2) on *Lilium*, Lawson ('98) on *Cobaea*, Nemeč ('99) on *Allium*, Debski ('97, '99) on *Chara*; also Belajeff ('94) and Farmer ('95).

of centres (without centrosomes), and thus give rise to an irregular multipolar figure (Figs. 36, 133). This figure finally resolves itself into a definite bipolar spindle which is devoid of centrosomes, and in the earlier stages also of asters, though in the later phases somewhat irregular asters are formed. On the basis of these observations Mottier¹ proposes to distinguish provisionally two well-defined types of mitosis in plants which he designates as the "thallophyte" and the "cormophyte" types. The latter seems wholly irreconcilable with the process observed in animal-cells; for the whole course of spindle-formation seems diametrically opposed in the two cases, and should the cormophyte-type be established it would, to say the least, greatly restrict the application of the centrosome-theory of Van Beneden and Boveri. Only future research can definitely determine the question.

There can be no doubt that the descriptions of Guignard and his followers do not rest upon pure imagination; for it is easy to observe at the spindle-poles in some preparations (*e.g.* sections of root-tips of *Allium*, *Lilium*, etc.) deeply staining-bodies such as these authors describe. These "centrosomes" seem, however, to be of quite inconstant occurrence; and the careful studies of

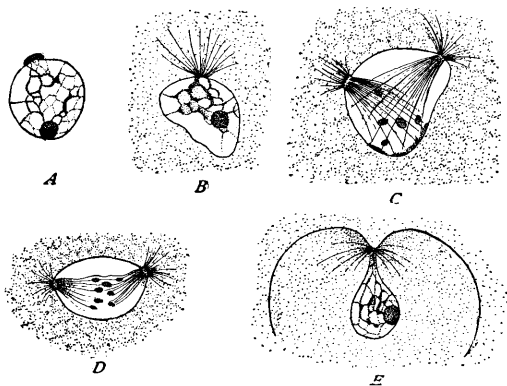


Fig. 33.—Mitosis in ascus-nuclei of a fungus, *Erysiphe*. [HARPER.]

A. Resting nucleus with disc-shaped centrosome (*c*). B. Early prophase with aster. C. Later prophase; amphister; intranuclear spindle forming. D. Spindle established. E. Daughter-nucleus after division; spore-membrane developing from astral rays.

Osterhout, Mottier, and Nemeč seem to give good ground for the conclusion that they have no such significance as the centrosomes of lower plants or of animals. It should nevertheless be borne in mind that true centrosomes ("blepharoplasts") have been demonstrated in the spermatogenic divisions of some of the vascular cryptogams, and that analogous bodies occur in the corresponding divisions of the cycads (p. 175). We should therefore still hold open the possibility that centrosomes may occur in the vegetative mitoses of the higher plants, their apparent absence being possibly due to lack of staining-capacity or similar conditions rendering their demonstration difficult.²

¹ '97, 2, p. 183.

² Mention may here be made of the barrel-shaped truncated spindles described in some of the plants. In *Basidiobolus*, Fairchild ('97) finds spindles of this type, having no asters

A no less remarkable mode of spindle-formation, which is in a certain way intermediate between the cormophyte-type and the usual animal type is described by Mead ('97, '98, 1) in the first maturation-division of *Chaetopterus*. Here the completed amphiaster is of quite typical form, and the centrosomes persist for the following mitosis; yet Mead is convinced that the amphiaster is synthetically formed by the union of two separate asters and centrosomes (Fig. 150) which

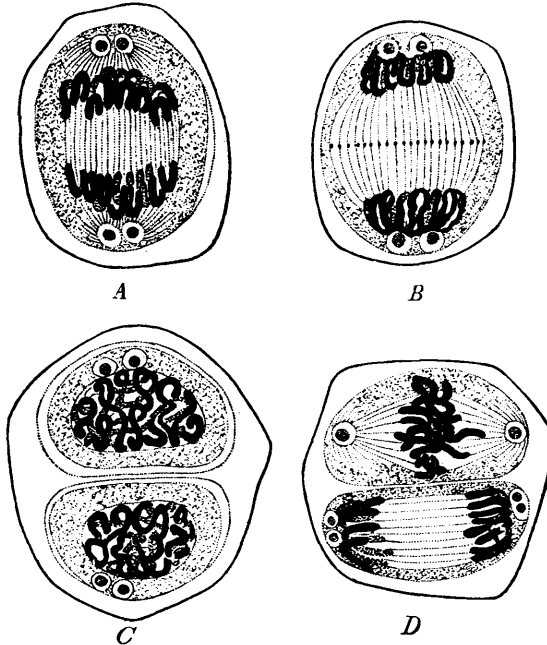


Fig. 34. — Division of pollen-mother-cells in the lily as described by GUIGNARD.

A. Anaphase of the first division, showing the twelve daughter-chromosomes on each side, the interzonal fibres stretching between them, and the centrosomes, already double, at the spindle-poles. *B.* Later stage, showing the cell-plate at the equator of the spindle and the daughter-spindres (dispireme-stage of Flemming). *C.* Division completed; double centrosomes in the resting cell. *D.* Ensuing division in progress; the upper cell at the close of the prophases, the chromosomes and centrosomes still undivided; lower cell in the late anaphase, cell-plate not yet formed.

have no genetic connection, arising independently *de novo* in the cytoplasm.¹ Improbable as such a conclusion may seem on *a priori* grounds, it is supported by very strong evidence,² and, taken together

and nearly parallel fibres, each of which terminates in a deeply staining granule. Nearly similar spindles have been described by Strasburger ('80) in *Spirogyra*, and in the embryo-sac of *Monotropa*. It is not impossible that such spindles may represent a type intermediate between the "cormophyte" and "thallophyte" types of Mottier.

¹ Cf. p. 306.

² I have had the privilege of examining some of Mead's beautiful preparations.

with the facts described in plants, it indicates that the forces involved in spindle-formation are far more complex than Van Beneden's and Boveri's hypothesis would lead one to suppose.¹

The centrosome and centrosphere appear to present great variations that have not yet been thoroughly cleared up and will be more critically discussed beyond.² They are known to undergo extensive changes in the cycle of cell-division and to vary greatly in different forms (Fig. 152). In some cases the aster contains at its centre nothing more than a minute deeply staining granule, which doubtless

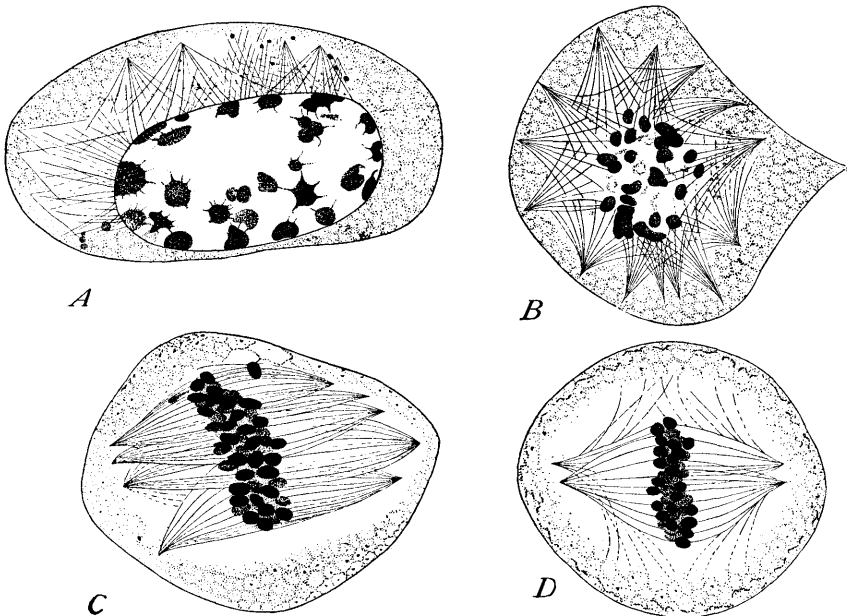


Fig. 36. — Division of spore-mother-cells in *Equisetum*, showing spindle-formation. [OSTERHOUT.]

A. Early prophase, "kinoplasmic" fibrillæ in the cytoplasm. B. Multipolar fibrillar figure invading the nuclear area, after disappearance of the nuclear membrane. C. Multipolar spindle. D. Quadripolar spindle which finally condenses into a bipolar one.

represents the centrosome alone. In other cases the granule is surrounded by a larger body, which in turn lies within the centrosphere or attraction-sphere. In still other cases the centre of the aster is occupied by a large reticular mass, within which no smaller body can be distinguished (*e.g.* in pigment-cells); this mass is sometimes called the centrosome, sometimes the centrosphere. Sometimes, again, the spindle-fibres are not focussed at a single point, and the spindle

¹ See p. 276 for the peculiar spindles, devoid of asters, observed during the maturation of the egg in certain forms. Cf. also Morgan's experiments on the artificial production of asters and centrosomes, p. 307.

² See p. 304.

appears truncated at the ends, its fibres terminating in a transverse row of granules (maturation-spindles of *Ascaris*, and some plant-cells). It is not entirely certain, however, that such spindles observed in preparations represent the normal structure during life.

b. The Chromatic Figure.—The variations of the chromatic figure must for the most part be considered in the more special parts of this work. There seems to be no doubt that a single continuous spireme-thread may be formed (*cf.* p. 113), but it is equally certain that the thread may appear from the beginning in a number of distinct segments, *i.e.* as a segmented spireme, and there are some cases in which no distinct spireme can be seen, the reticulum resolving itself directly into the chromosomes. The chromosomes, when fully formed, vary greatly in appearance. In many of the tissues of adult plants and animals they are rod-shaped and are often bent in the middle like a V (Figs. 28, 131). They often have this form, too, in embryonic cells, as in the segmentation-stages of the egg in *Ascaris* (Fig. 31) and other forms. The rods may, however, be short and straight (segmenting eggs of echinoderms, etc.), and may be reduced to spheres, as in the maturation-stages of the germ-cells. In the equatorial plate the V-shaped chromosomes are placed with the apex of the V turned toward the spindle (Fig. 28), while the straight rods are placed with one end toward the spindle. In either case the daughter-chromosomes first begin to move apart at the point nearest the spindle, the separation proceeding thence toward the free portion. The V-shaped chromosomes, opening apart from the apex, thus give rise in the early anaphase to <>-shaped figures; while rod-shaped chromosomes often produce λ - and \perp -shaped figures (the stem of the \perp being double). The latter, opening farther apart, form straight rods twice the length of the original chromosome (since each consists of two daughter-chromosomes joined at one end). This rod finally breaks across the middle, thus giving the deceptive appearance of a transverse instead of a longitudinal division (Fig. 52). The <>-shaped figures referred to above are nearly related to those that occur in the so-called *heterotypical mitosis*. Under this name Flemming ('87) first described a peculiar modification of the division of the chromosomes that has since been shown to be of very great importance in the early history of the germ-cells, though it is not confined to them. In this form the chromosomes split at an early period, but the halves remain united by their ends. Each double chromosome then opens out to form a closed ring (Fig. 37), which by its mode of origin is shown to represent two daughter-chromosomes, each forming half of the ring, united by their ends. The ring finally breaks in two to form two U-shaped chromosomes which diverge to opposite poles

of the spindle as usual. As will be shown in Chapter V., the divisions by which the germ-cells are matured are in many cases of this type; but the primary rings here in many cases represent not two but four chromosomes, into which they afterward break up.

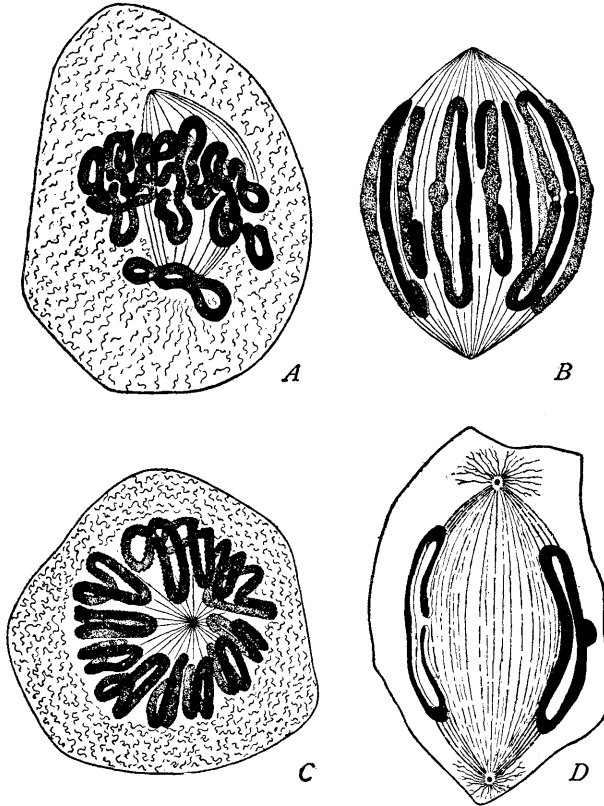


Fig. 37. — Heterotypical mitosis in spermatocytes of the salamander. [FLEMMING.]

A. Prophase, chromosomes in the form of scattered rings, each of which represents two daughter-chromosomes joined end to end. B. The rings ranged about the equator of the spindle and dividing; the swellings indicate the ends of the chromosomes. C. The same viewed from the spindle-pole. D. Diagram (Hermann) showing the central spindle, asters, and centrosomes, and the contractile mantle-fibres attached to the rings (one of the latter dividing).

2. Bivalent and Plurivalent Chromosomes

The last paragraph leads to the consideration of certain variations in the number of the chromosomes. Boveri discovered that the species *Ascaris megalocephala* comprises two varieties which differ in no visible respect save in the number of chromosomes, the germ-nuclei of one form ("variety bivalens" of Hertwig) having two chromosomes,

while in the other form ("variety univalens") there is but one. Brauer discovered a similar fact in the phyllopod *Artemia*, the number of somatic chromosomes being 168 in some individuals, in others only 84 (p. 281).

It will appear hereafter that in some cases the primordial germ-cells show only half the usual number of chromosomes, and in *Cyclops* the same is true, according to Häcker, of all the cells of the early cleavage-stages.

In all cases where the number of chromosomes is apparently reduced ("pseudo-reduction" of Rückert) it is highly probable that each chromatin-rod represents not one but two or more chromosomes united together, and Häcker has accordingly proposed the terms *bivalent* and *plurivalent* for such chromatin-rods.¹ The truth of this view, which originated with Vom Rath, is, I think, conclusively shown by the case of *Artemia* described at page 281, and by many facts in the maturation of the germ-cells hereafter considered. In *Ascaris* we may regard the chromosomes of Hertwig's "variety univalens" as really bivalent or double, *i.e.* equivalent to two such chromosomes as appear in "variety bivalens." These latter, however, are probably in their turn plurivalent, *i.e.* represent a number of units of a lower order united together; for, as described at page 148, each of these normally breaks up in the somatic cells into a large number of shorter chromosomes closely similar to those of the related species *Ascaris lumbricoides*, where the normal number is 24.

Häcker has called attention to the striking fact that plurivalent mitosis is very often of the heterotypical form, as is very common in the maturation-mitoses of many animals (Chapter V.), and often occurs in the early cleavages of *Ascaris*; but it is doubtful whether this is a universal rule.

3. *Mitosis in the Unicellular Plants and Animals*

The process of mitosis in the one-celled plants and animals has a peculiar interest, for it is here that we must look for indications of its historical origin. But although traces of mitotic division were seen in the Infusoria by Balbiani ('58-'61), Stein ('59), and others long before it was known in the higher forms, it has only recently received adequate attention and is still imperfectly understood.

Mitotic division has now been observed in many of the main divisions of Protozoa and unicellular plants; but in the present state of

¹ The words *bivalent* and *univalent* have been used in precisely the opposite sense by Hertwig in the case of *Ascaris*, the former term being applied to that variety having *two* chromosomes in the germ-cells, the latter to the variety with one. These terms certainly have priority, but were applied only to a specific case. Häcker's use of the words, which is strictly in accordance with their etymology, is too valuable for general descriptive purposes to be rejected.

the subject it must be left an open question whether it occurs in all. In some of the gregarines and Heliozoa, the process is of nearly or quite the same type as in the Metazoa. From such mitoses, however, various gradations may be traced toward a much simpler process, such as occurs in *Amæba* and the lower flagellates; and it is not improbable that we have here representatives of more primitive conditions. Among the more interesting of these modifications may be mentioned:—

1. Even in forms that nearly approach the mitosis of higher types

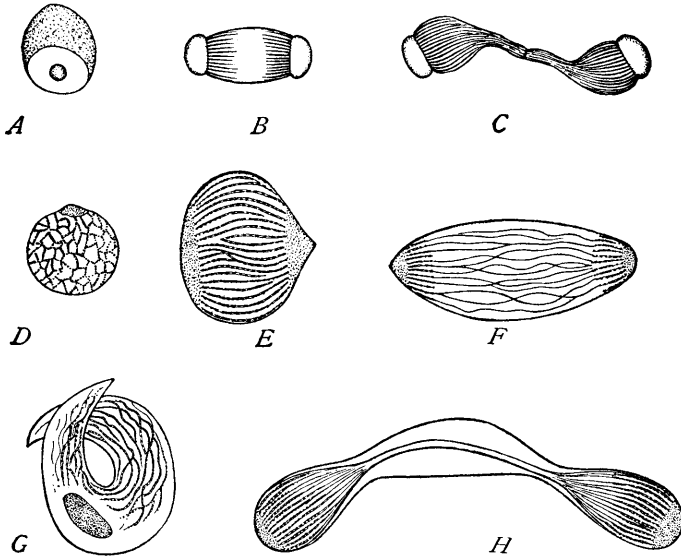


Fig. 38.— Mitotic division in Infusoria. [R. HERTWIG.]

A-C. Macronucleus of *Spirochona*, showing pole-plates. D-H. Successive stages in the division of the micronucleus of *Paramecium*. D. The earliest stage, showing reticulum. G. Following stage ("sickle-form") with nucleolus. E. Chromosomes and pole-plates. F. Late anaphase. H. Final phase.

the nuclear membrane may persist more or less completely through every stage (*Noctiluca*, *Euglypha*, *Actinosphaerium*).

2. Asters may be present (Heliozoa, gregarines) or wanting (Infusoria, Radiolaria).

3. In one series of forms the centrosome or sphere is represented by a persistent intranuclear body (nucleolo-centrosome) of considerable size, which divides to form a kind of central spindle (*Euglena*, *Amæba*, Infusoria?).

4. In a second series the centrosome or sphere is a persistent

extranuclear body, as in most Metazoa (*Heliozoa*, *Noctiluca*, *Paramæba*).

5. In a few forms having a scattered nucleus the chromatin-granules are only collected about the apparently persistent sphere or centrosome at the time of its division, and afterward scatter through the cell, leaving the sphere lying in the general cell-substance (*Tetramitus*).

6. The arrangement of the chromatin-granules to form chromosomes appears to be of a secondary importance as compared with

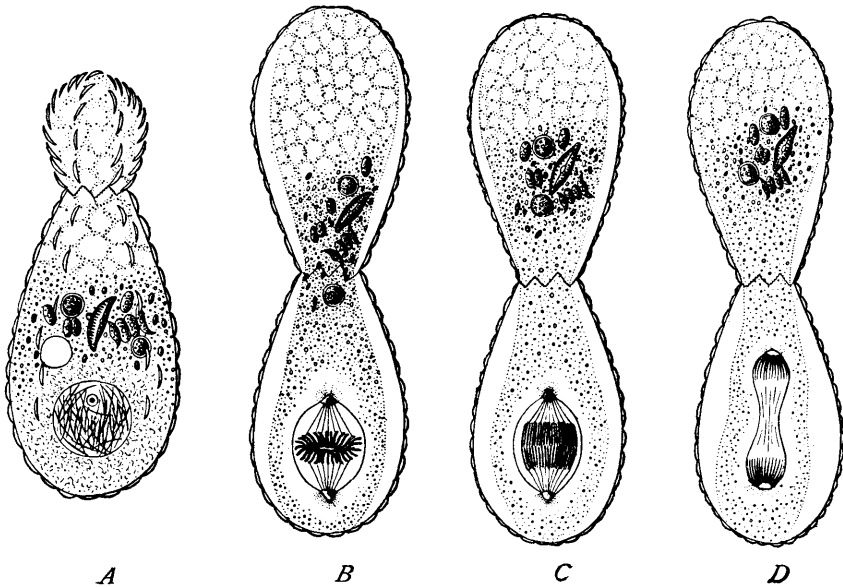


Fig. 39.—Mitosis in the rhizopod, *Euglypha*. [SCHEWIAKOFF.]

In this form the body is surrounded by a firm shell which prevents direct constriction of the cell-body. The latter therefore divides by a process of budding from the opening of the shell (the initial phase shown at *A*); the nucleus meanwhile divides, and one of the daughter-nuclei afterward wanders out into the bud.

A. Early prophase; nucleus near lower end containing a nucleolus and numerous chromosomes. *B.* Equatorial plate and spindle formed inside the nucleus; pole-bodies or pole-plates (*i.e.* attraction-spheres or centrosomes) at the spindle-poles. *C.* Metaphase. *D.* Late anaphase, spindle dividing; after division of the spindle the outer nucleus wanders out into the bud.

higher forms, and the essential feature in nuclear division appears to be the fission of the individual granules.

We may first consider especially the achromatic figure. The basis of our knowledge in this field was laid by Richard Hertwig through his studies on an infusorian, *Spirochona* ('77), and a rhizopod, *Actinosphaerium* ('84). In both these forms a typical spindle and equatorial plate are formed *inside the nuclear membrane* by a direct transformation of the nuclear substance. In *Spirochona* (Fig. 38, *A-C*) a

hemispherical "end-plate" or "pole-plate" is situated at either pole of the spindle, and Hertwig's observations indicated, though they did not prove, that these plates arose by the division of a large "nucleolus." Nearly similar pole-plates were somewhat described by Schewiakoff ('88) in *Euglypha* (Fig. 39), and it seems clear that they are the analogues of the centrosomes or attraction-spheres in higher forms. In *Euglena*, as shown by Keuten, the pole-plates, or their analogues, certainly arise by division of a distinct and persistent intranuclear body ("nucleolus" or "nucleolo-centrosome") which elon-

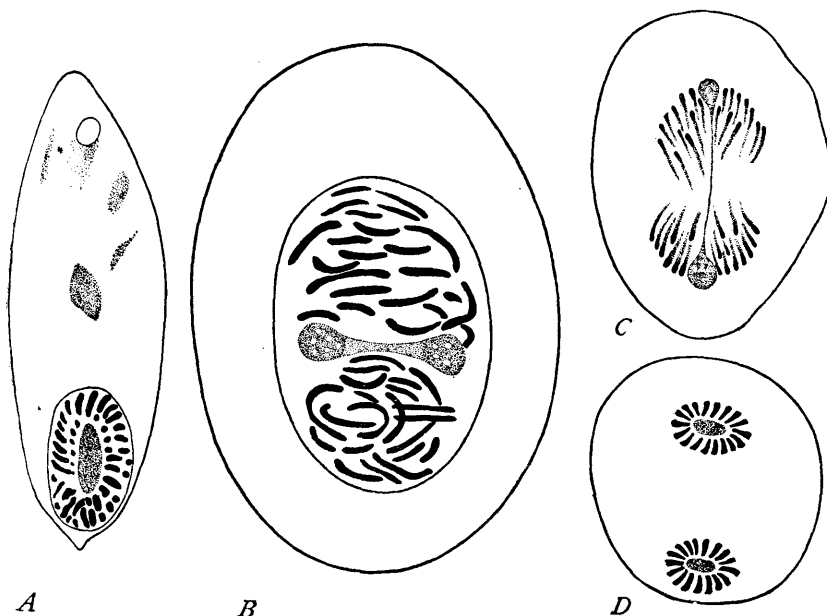


Fig. 40.—Mitosis in the flagellate, *Euglena*. [KEUTEN.]

A. Preparing for division; the nucleus contains a "nucleolus" or nucleolo-centrosome surrounded by a group of chromosomes. B. Division of the "nucleolus" to form an intranuclear spindle. C. Later stage. D. The nuclear division completed.

gates to form a kind of central spindle around which the chromatin elements are grouped (Fig. 40); and Schaudinn ('95) described a similar process in *Amæba*. Richard Hertwig's latest work on *Infusoria* ('95) indicates that a similar process occurs in the micronuclei of *Paramæcium*, which at first contain a large "nucleolus" and afterward a conspicuous pole-plate at either end of the spindle (Fig. 38, D-H). The origin of the pole-plates was not, however, positively determined. A corresponding dividing body is found in *Ceratium* (Lauterborn, '95), and as in the *Infusoria* the entire nucleus transforms itself into a fibrillar spindle-like body.

Still simpler conditions are found in some of the flagellates.¹ In *Chilomonas* the sphere may still be regarded as intranuclear, since it lies in the middle of an irregular mass of chromatin-granules, though the latter are apparently not enclosed by a membrane. Nuclear division is here accomplished by fission of the sphere and the aggregation of the chromatin-granules around the two products. In *Tetramitus*, finally (Fig. 16), the nucleus is represented by chromatin-granules that are scattered irregularly through the cell and only at the time of division collect about the dividing sphere.

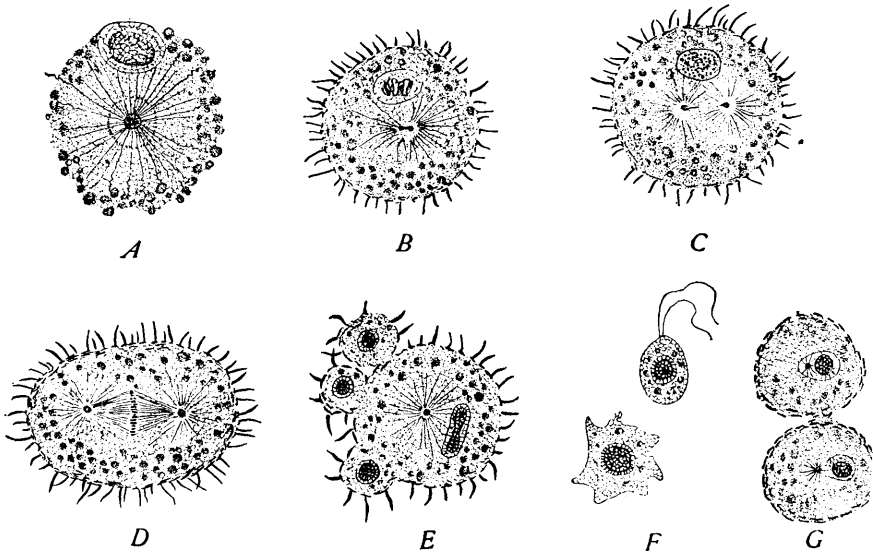


Fig. 41. — Mitosis in the Heliozoa. [SCHAUDINN.]

A. *Sphaerastrum*; vegetative cell showing nucleus, "central granule" (centrosome), and axial rays. B-G. *Acanthocystis*. B-D. Prophases of mitosis. E. Budding to form swarm-spores. F. Swarm-spores, devoid of centrosomes. G. Swarm-spores preparing for division; intranuclear origin of centrosome.

In a second series of forms, represented by *Noctiluca* (Ishikawa, '94, '98), (Calkins, '98, 2), *Paramæba* (Schaudinn, '96, 1), *Actinophrys* and *Acanthocystis* (Schaudinn, '96, 2), and the diatoms (Lauterborn, '96), the sphere lies outside the nucleus in the cytoplasm and the mitosis is closely similar to that observed in most Metazoa. This is most striking in the Heliozoa, where the centrosome persists through the vegetative condition of the cell as the "central granule," to which the axial filaments of the pseudopodia converge. Schaudinn ('96, 2) shows that by the division of this body a typical extranuclear amphister and central spindle are formed (Fig. 41), while the chromatin

¹ Calkins, '98, 1, '98, 2.