of the first division has reappeared during the anaphase. At the beginning of the second division the daughter centrosomes move through an angle of ninety degrees, and a spindle is formed with the chromosomes arranged in an equatorial plate. They are arranged now so that the split is at right angles to the spindle. During the anaphase the halves of the chromosomes are drawn to opposite poles (*O* and *P*, Fig. 3929).

The secondary spermatocyte then divides, forming two *spermatids*. The change from a group of chromosomes to a resting nucleus, which ensues at this stage, is peculiar in that it is effected by the swelling of the chromosomes. A vacuole appears in each chromosome, so that each one becomes a small vesicle. These vesicles uniting form the resting nucleus, around which there is finally developed a nuclear membrane.

The history of the spermatid in the final period of histogenesis, during which it becomes transformed into a functional spermatozoon, will be treated elsewhere (see article *Spermatozoa*).

The Maturation of the Egg.—The parallel between the course of development of the egg and that of the spermatozoon in their external features has been pointed out in a preceding paragraph. The parallel extends also to the nuclear changes, as was first clearly suggested by Platner in 1889. Comparison of the processes of spermatogenesis and oögenesis in Ascaris led Boveri to make a more positive statement in 1890, and its truth was completely demonstrated, so far as Ascaris is concerned, by O. Hertwig a few months later.

These discoveries relate chiefly to the divisions of the chromosomes. The synapsis stage was first clearly recognized in the development of eggs by Woltereck (1898) through his studies on the Ostracoda. In 1900 von

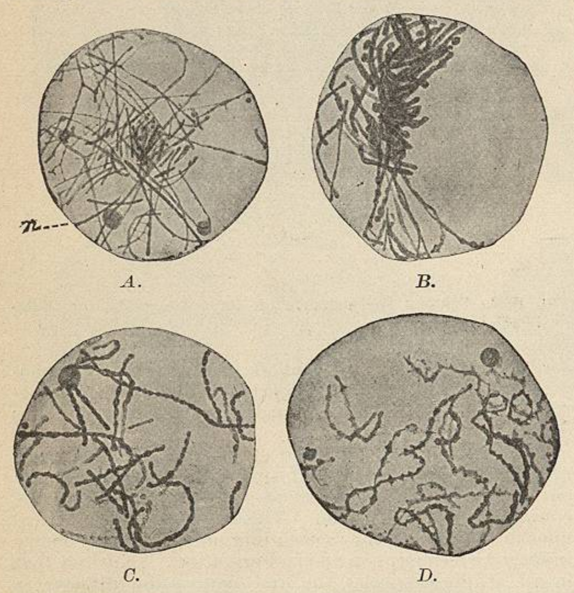

FIG. 3933.—Nuclei from the Ovary of a Human Fœtus of about Seven Months, showing consecutive stages in the development of the oöcycte. *B*, Synapsis; *n*, nucleolus. × 1700. (After Winiwarter.)

Winiwarter published an elaborate description of this stage in the history of mammalian ova (Fig. 3933). An abstract of his results is given in the article *Ovum*.

As in the corresponding stages in spermatogenesis, shortly after the last division of oögonia, the nuclei of the young oöcytes pass through the synapsis stage, characterized by the massing of chromatin filaments at one side of the nucleus (Fig. 3933 *B*). The chromosomes emerge from the tangle with their number reduced to half the number present during the previous anaphase. These chromosomes are, or soon become, split longitudinally. They continue to elongate, and finally the nucleus enters into the resting condition. It remains in this condition during the growth period, during which the oöcyte increases enormously in size. This period may extend through many years, as in man.

Just before, or very soon after, the egg is discharged from the ovary the first maturation division occurs, which results in the budding off of the very small first polar body from the egg, which then becomes a secondary oöcyte. The nuclear phenomena at this time are exactly like those to be observed during the division of the primary spermatocytes of the same species.

In the same way the process of formation of the second polar body is like the division of the secondary spermatocytes of the same species.

Thus the processes of oögenesis and spermatogenesis are parallel in every essential particular; the main difference being that in the maturation divisions of the spermatocytes, the resulting cells are equal in size, while those that result from the divisions of the oöcytes are very unequal; and the spermatids undergo a further metamorphosis associated with the special function of the spermatozoa, a change which the special function of the egg renders entirely unnecessary.

Variations in the Process of Maturation.—The forms of the chromosomes and the details of their divisions during maturation differ widely in different groups of animals, and this has resulted in various interpretations of the process by different writers.

Many authors have confirmed Weismann's prediction that a reducing division takes place. But they are not all agreed as to the time when the reducing division occurs. Weissmann predicted on theoretical grounds that the reducing division would occur during the formation of the second polar body. Paulmier and Montgomery found, on the contrary, that in Hemiptera the first is a reducing division, the second an equal division. Similar results were obtained previously by Koscheldt in an annelid, Ophryotrocha, by Wilcox in a grasshopper, Caloptenus, and by Henking in a firefly, Pyrrhocoris. On the other hand, Häcker, von Rath, and Rückert are agreed that in the copepoda the reducing division comes after an equal division, as predicted by Weismann. Similar results have been obtained by von Rath in the mole cricket, Gryllotalpa, by Calkins in the earth-worm, Lumbricus, by Griffin in Thalassema, and by Sutton in Brachystola.

In Ascaris and various vertebrates, chiefly selachians and amphibia, it has been found that both maturation divisions are accompanied by longitudinal splitting of the chromosomes, and authors working upon these forms have been led thus to deny the existence of any reducing division. In Ascaris the two chromosomes, which appear in the oöcyte preparing for division, are elongated and split longitudinally in two planes at right angles to one another. By the shortening of these rods each chromosome becomes a typical tetrad, which divides in the usual manner; that is, in the first maturation each tetrad divides, forming two dyads. One dyad of each pair remains in the egg and separates into two single chromosomes, one of each pair going to the second polar body, so that the first polar body receives two dyads, the second polar body and the ripe egg each two single chromosomes.

In the vertebrates the chromosomes in the spermatocytes preparing for the first division are U-shaped. At an early period a longitudinal split appears at the bend of the U, but the two halves remain united at the ends and open out to form a ring (Fig. 3931). In the metaphase the ring-shaped chromosomes separate into two U's by breaking across at the points of union (Fig. 3932). This form of mitosis was called *heterotypical* by Flemming, and is highly characteristic of this stage in the vertebrates. In the next division each chromosome again splits longitudinally. Montgomery has rightly contended that it does not necessarily follow that both divisions are equal, even if they are both longitudinal. In the Hemiptera it was shown that the chromosomes of the first spermatocyte are bivalent, having been formed by the union

of two univalent chromosomes end to end, and it is perfectly possible that in the vertebrates the corresponding bivalent chromosomes are formed by the union of two univalent ones side by side. In this case one of the longitudinal splittings would be a true reducing division, separating the original chromosomes or the halves of originally separate ones. This question can be settled only by a very careful study of the fusion of the chromosomes during synapsis.

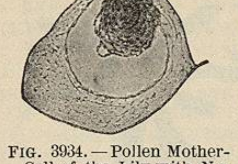

FIG. 3934.—Pollen Mother-Cell of the Lily with Nucleus in Synapsis. × 585. (After Sargant.)

Reduction in Plants.—In the vascular cryptogams and the flowering plants the phenomena attending a reduction in the number of chromosomes preparatory to sexual reproduction are closely parallel with those found in animals, but present interesting differences.

In these plants the cell corresponding to the last generation of oögonia or spermatogonia in animals usually lies just beneath the epidermis and divides parallel to the surface into an outer *tapetal cell* and an inner cell, the *archesporium*. The mitosis is typical with the normal number of chromosomes. When the archesporium prepares for division the chromosomes reappear reduced in number to one-half, and the normal number is not restored until the male and female pronuclei unite in fertilization. Usually the archesporium divides twice in rapid succession. The result in the Hepaticæ and ferns is the production of four spores. Each spore may then divide by typical mitosis, but with half the normal number of chromosomes. It thus, by continued cell division, forms a prothallium, which exists for some time as an independent plant, and bears the sexual organs, in which the ova and spermatozoa are produced.

In the male flowering plants, the archesporium gives rise to four pollen grains. It is not, however, the primary nucleus of the pollen grain that forms the male pronucleus, but it is its granddaughter nucleus. In the female flowering plants Schniewind-Thies (1901) has found three types of development. In the first the archesporium divides into two daughter cells, and each of these divides into two, making four cells in a row perpendicular to the surface. One of these cells is the young "embryo sac," the others are cover cells, which subsequently undergo degeneration, and may be compared to the polar bodies of animals. Within the embryo sac three nuclear divisions occur, and one of the resulting nuclei is the female pronucleus. In the second type the archesporium divides into two daughter cells, one of which becomes the embyro sac, in which three divisions occur as before. Finally in the third type the archesporium itself becomes the embryo sac. In each case the reduced number of chromosomes first appears in the archesporium and the divisions of the archesporium and its two daughter cells differ from the typical mitoses, being described as heterotypical and homœotypical respectively. These terms were applied originally to the first and second maturation divisions in vertebrates, and their use here indicates the striking similarity of the phenomena.

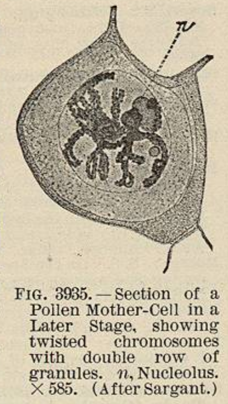

FIG. 3935.—Section of a Pollen Mother-Cell in a Later Stage, showing twisted chromosomes with double row of granules. *n*, Nucleolus. × 585. (After Sargant.)

As to whether a reducing division does or does not take place, opinion is much divided. Some good observers, notably Ishikawa and Belajeff, regard the first as an equal division and the second as a reducing division. But the majority of authorities, led by Strasburger, insist that both divisions are equal.

This result may be due in part to the fact that most of these authors have completely ignored the synapsis stage, and in their search for a reducing division, undoubtedly influenced by Weismann and Häcker, have concentrated their attention upon the daughter cells instead of upon the archesporium.

The history of both the pollen grain and the embryo sac of *Lilium martagon* has been studied and described with great care by Miss Sargant. In both series she finds a typical synapsis; but it is at the end, instead of at the beginning, of the growth period (Fig. 3934). The chromatic filaments, which showed signs of splitting before the synapsis, emerge from that stage as long flattened bands of linin bearing a row of chromatin granules upon each edge, as in Peripatus. These bands are bent and twisted together (Fig. 3935). As the chromosomes become more condensed the granules merge into a solid mass of chromatin, apparently covering up the linin; and when it reaches its place at the equator of the spindle, each chromosome is composed of two limbs tightly twisted together, giving the appearance of a minute skein of yarn; or, better, a very much twisted doughnut. In the metaphase the two limbs of the chromosomes are separated, and as they are pulled apart, they often assume a V shape; and apparently the original longitudinal split may reappear at this stage, as is indicated by Strasburger's figures. At any rate Miss Sargant finds, and her results are confirmed by many others, that in the second division the chromosomes are separated into two equal halves by a longitudinal split.

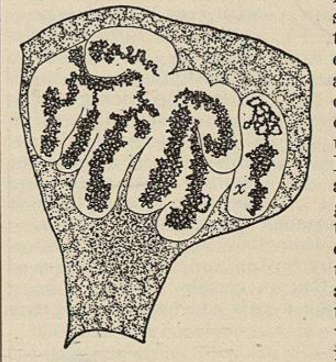

FIG. 3936.—Spermatogonium of Lubber Grasshopper in Early Prophase, showing very fine spiremes arranged in their respective diverticula of the nucleus. From a section. (After Sutton.)

But, aside from their inferences to the contrary, the writer is unable to find anything in the facts, as shown by the descriptions and figures published by Miss Sargant, Strasburger, Farmer, and Schniewind-Thies, that is inconsistent with the inference that the chromosomes previous to the first division are bivalent, formed by the union during synapsis of two univalent chromosomes end to end, and that the two limbs separated during the anaphase are originally independent chromosomes.

That the apparent reduction in the archesporium previous to division may be due to fusion of pairs of chromosomes end to end, was suggested by Strasburger in 1894, and Farmer, who first clearly recognized the synapsis stage in plants, suggested in 1895 that the *first* one might be a true reducing division, separating the univalent constituents of bivalent chromosomes. But he regarded this view as untenable, "for in animals no 'reduction' is claimed at this stage." Now the work of Montgomery, Paulmier, and others has made it clear that reduction may occur in animals at this stage, the first maturation division, and thus the chief ground for deny-

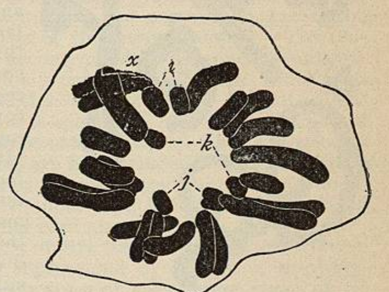

FIG. 3937.—Polar View of Equatorial Plate of Spermatogonium, showing twenty-two chromosomes and accessory, *x*; *i*, *j*, *k*, three pairs of small chromosomes. From a section. (After Sutton.)

ing the existence of reducing division in plants appears to have been removed. Moreover, the similarity is so close at this stage that many of the figures drawn by Strasburger, Miss Sargant, and Schniewind-Thies to illustrate forms of chromosomes in plants might be substituted for some of Paulmier's or Montgomery's figures, representing corresponding stages, with very little change.

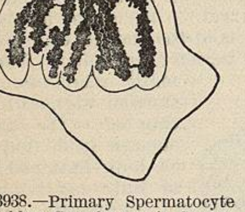

FIG. 3938.—Primary Spermatocyte of Lubber Grasshopper in Synapsis (telophase of spermatogonium). Only a few of the chromosomes are shown. (After Sutton.)

Synapsis, Reduction, and Heredity.—As stated in the introduction, the conception "reducing division" had its origin in an attempt to satisfy the requirements of a theory of heredity. The conception has very recently gained new interest and importance through an announcement made by E. B. Wilson (1902) and the publication of preliminary papers by Sutton and Cannon. It was found by Montgomery that in certain species of bugs the spermatogonia contain a pair of chromosomes that are unusually large or otherwise peculiar, and that after the synapsis in these cases there is only one large chromosome. Evidently the two peculiar ones have united. As a result of the maturation divisions each spermatid likewise contains one peculiar chromosome. The same is probably true of the egg. So one of these bodies in the spermatogonium is probably of paternal and the other of maternal origin. For this and other reasons Montgomery reaches the important conclusion that during the synapsis each bivalent chromosome formed is half of paternal and half of maternal origin, and the subsequent reducing division results in the separation of homologous paternal and maternal elements and their final isolation in separate germ cells.

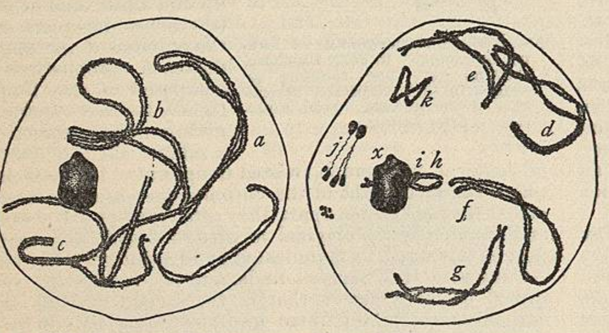

FIG. 3939.—Spiremes, or Chromosomes, from a Primary Spermatocyte in Early Prophase. Drawn in two groups to avoid confusion. From a smear preparation. (After Sutton.)

FIG. 3940.—Chromosomes from Primary Spermatocyte in Middle Prophase, showing Longitudinal Split. *a, b, c,* etc., same as in Fig. 3939. (After Sutton.)

Now, as announced by Wilson, W. S. Sutton has found in the study of the spermatogenesis of a grasshopper, Brachystola, nearly complete proof of this inference, and W. A. Cannon has come to the same conclusion from the study of the maturation divisions of hybrid cotton plants. The chief results of Sutton's work are illustrated by Figs. 3936 to 3941. The last generation of spermatogonia have lobed nuclei, and each chromosome is formed in a separate diverticulum (Fig. 3936). In the late prophase of division the chromosomes are seen to be of different sizes, and there is one pair of each size, as *i, j, k,* Fig. 3937. In the following synapsis stage the chromosomes are seen to unite in pairs by their ends (Fig. 3938) and in the subsequent prophase there are eleven bivalent chromosomes, *a, b, c . . . k,* Figs. 3939 and 3940, corresponding to the pairs in the spermatogonium. The second maturation division is a true reducing division (Fig. 3941). If the oögenesis is the same, and the individuality of the chromosomes is maintained throughout the germinal cycle, then, of the two chromosomes that unite in synapsis, one must be of paternal and the other of maternal origin.

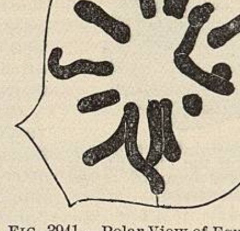

FIG. 3941.—Polar View of Equatorial Plate of Secondary Spermatocyte, showing eleven chromosomes and the accessory, *x*. (After Sutton.)

It was discovered recently by Boveri, that when the chromosomes in the segmenting ovum of a sea urchin have become disarranged as the result of double fertilization, and consequently unequally distributed to the blastomeres, abnormal larvæ result. He inferred from this that the chromosomes differ qualitatively and stand in definite relation to inheritable characters.

Taking all these results together, Wilson points out that they seem to confirm and to show a physical basis for Mendel's principle of heredity, which is being much discussed at present (see *Reversion*). Whether Mendel's theory be true or not, it is certain, as was shown in the article dealing with heredity, that it is in the nucleus of the germ cells, and especially in their chromatin constituents, that we must look to find the physical basis for heredity, and therefore the changes which these constituents undergo in the course of sexual reproduction possess the deepest interest for all students of biology.

Robert Payne Bigelow.

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REEDY CREEK SPRINGS.—Marion County, South Carolina. POST-OFFICE.—Latla. Hotel and cottages.

This resort is located about three-quarters of a mile from the Atlantic Coast Line Railroad. The surrounding country is level and covered by the long-leafed pine. The springs are three in number, and have had a local reputation for more than thirty years. The water has a constant temperature of 45° F., and its flow is very large. Mr. John L. Dew, of the springs, sends us the following list of ingredients resulting from a partial analysis by former State Chemist Chizzell: Iron carbonate, calcium, magnesium, and sulphur. The water is used more particularly for stomach, liver, and kidney disorders and debilitated states of the system.

James K. Crook.

REFLEX ACTIONS OR REFLEXES. See *Knee-Jerk*.

REFLEXES. (CLINICAL.)—Descartes introduced the conception of reflexes into biological literature. In "Passions de l'âme" he stated that stimulation of a sensory nerve impulse may be transmitted through the brain to motor nerves and thereby give rise to contraction of muscles, and that this contraction takes place without volition, and even contrary to it. The general reflex centre he believed to be the glandula pinealis.

This definition of reflexes was correct in the early days of biology, but, with the advance of knowledge, our conception of the reflexes has been enlarged.

The term is used in medical literature to-day in a twofold sense:

1. *Specifically*, as in pupillary, knee, plantar reflexes, etc.

2. *Generically*, as in reflex neurosis, reflex spasms, reflex cough, etc.

In both the strict sense (pupillary and knee reflexes, etc.) and in the broader sense (reflex cough, reflex neurosis, etc.) reflexes are centrifugal phenomena produced by reflexion and eventual transmutation of centripetal stimulation. In other words, reflexes are physiological or pathological, motor, vaso-motor, viscero-motor, secretory or trophic phenomena, the cause of which is to be found in sensory stimulation.

There is still another group of phenomena called "reflex," to which the foregoing definition does not apply. This group is represented by a set of *centripetal* phenomena—reflex pains, reflex neuralgias, etc. Investigation shows that these phenomena are not genuine reflexes. One group of them, for instance pain in the distribution of the fifth nerve due to disease of the teeth or other structures of the head, or arm pain accompanying an anginoid attack, is, according to Head, an irradiation of a sensory stimulus to other parts or branches of the peripheral sensory apparatus of the affected locality.

Another group, for instance headache due to disease of the abdominal viscera, is, according to the same author, due to irradiations of the sensory stimulation to a central sensory station, and from here to allied sensory structures. Thus the difference between the two types becomes quite apparent.

The genuine reflex phenomena consist of neural stimulation that is reflected from one set of neurones (centripetal neurones) to a physiologically different set of neurones (centrifugal neurones).

The other type consists of neural stimulation that is irradiated and propagated from one set of neurones (centripetal) to another physiologically homologous set (centripetal neurones).

Finally, the term reflex is used promiscuously in medical literature to denote a phenomenon, the cause of which operates at some distance from where its effects are manifest.

According to the conception of genuine reflexes outlined above, all organic functions, save perhaps the distinctly voluntary functions, and some automatic visceral functions, may be looked upon as reflexes. Whether this be fully so or not, we will not attempt to decide. The considerable interest bestowed upon these phenomena, since the times of Descartes, testifies to the great importance of reflexes. (For further details in regard to these, consult the article on *Knee-Jerk* in Vol. V.)

In 1875 Erb and Westphal, working independently, demonstrated the clinical value of reflex phenomena, and since then their importance is daily more appreciated.

Prior to the publications of Erb and Westphal reflexes were observed and registered at the bedside in Charcot's Clinic. Charcot apparently divined their importance, but he had not yet appreciated their clinical significance.

Abundant clinical, experimental, and histological facts have been collected for the proper theoretical interpretation of reflex phenomena. However, a unanimity of opinion has not yet been reached. Some accept the original teachings of Erb, who interpreted reflexes, particularly tendon reflexes, as true reflexes; others adhere to Westphal's teaching, who believed that they were not true reflexes, but phenomena dependent upon the muscle tonus. Gowers calls the tendon reflexes myotatic phenomena, and his conception is akin to that of Westphal.

We shall not consider here the evidence which tends to substantiate either of these theoretical views. Here the theoretical basis of the reflex phenomena will be discussed only in so far as is necessary for a proper and intelligent interpretation of these phenomena at the bedside. The best-known and most studied of all reflexes are the tendon reflexes, and their classical representative is the knee-jerk.

The subsequent remarks apply to tendon reflexes in general, and to the knee-jerk in particular.

A reflex is a neural phenomenon which originates in a sensory end organ, travels along a centripetal pathway, passes a ganglionic station, and leaves it changed or unchanged in quality or quantity, and pursues its way outward on a centrifugal pathway to a centrifugal end organ. The anatomical structure subserving this consists of: A sensory end organ, a peripheral sensory fibre, a ganglion cell, a peripheral motor fibre, a motor end-organ—in other words, a sensory and a motor neurone of the peripheral kind.

This anatomical structure is called a reflex arc. The primary reflex arc is under the influence of one or more secondary arcs, which are represented by an analogous arrangement of secondary neurones.

The centrifugal branch of one of the supposed secondary arcs is represented by the fibres of the pyramidal tracts. The centripetal partner and the central connection of the two are not fully known. The former is probably found in the ascending cerebral and cerebellar tracts, and the central station is probably situated in the gray matter of the cerebrum and cerebellum, and in the nuclei and gray matter of the mesencephalon. The tendon phenomena are accompanied by conscious sensation. Whether this sensation is carried up along the centripetal pathways above mentioned or not is not known. Usually, when a reflex arc is spoken of, only the strict neural elements are understood to represent it, while the sensory and motor end-organs are not included. The ganglionic stations are spoken of as reflex centres. In addition a reflex arc is under the modifying influence of individual segments of the spinal cord above it.

In the lowest forms of life the anatomical substratum of most reflexes is represented by one reflex arc only. This is the case also in some of the simpler forms of reflexes.

All that has been said thus far applies particularly to the tendon phenomena. For other reflexes, skin reflexes, visceral reflexes, etc., analogous anatomical structures are supposed to exist. Their exact location and connections are fully known in some instances, not entirely in others, while in still others they are altogether hypothetical.