duced hæmoglobin, but agitating the blood with air will reproduce the oxyhæmoglobin. When, however, carbon monoxide (CO), carbonic oxide, is introduced into blood, we get a new condition which gives a spectrum resembling, but not identical with, that of oxyhæmoglobin, there being two bands, but their position being slightly nearer the violet.

Furthermore, we cannot so easily restore the original condition by agitating the blood with air, nor will the ordinary reducing agents produce the spectrum of reduced hæmoglobin. Carbon monoxide is known to be one of the most active of the gaseous narcotic poisons, and the above observations show, in part at least, the peculiar action it has on the essential breathing constituent of the blood. The carbon-monoxide-hæmoglobin spectrum is seen in the blood of persons poisoned by water-gas or fumes of burning charcoal, and an examination of the blood by the spectroscope in cases of this character may be an important medico-legal point. Another important modification of the hæmoglobin is produced by the action of sulphides, especially by hydrogen sulphide (H_2S), sulphureted hydrogen. This gas is often present in sewer air, cesspool exhalations, and in other foul places, but not invariably, nor in so great quantity as is generally supposed. When its action upon blood is examined we find a spectrum which presents the broad single absorption band of reduced hæmoglobin (see above), but in addition a band in the red just at the junction with the orange. This band does not disappear on shaking the blood with air, although the two bands of oxyhæmoglobin appear. The body produced by the action of hydrogen sulphide on blood, and to which the properties above described are due, has been called *sulphæmoglobin*. It has been noticed that this substance cannot be formed by the action of hydrogen sulphide on reduced hæmoglobin, which is the form that exists in the veins; hence hydrogen sulphide may be introduced into the venous circulation without marked effect, but taken into the arterial system it is very dangerous. The difference between inhalations of this gas, by which it would get directly into arterialized blood, and its introduction into the system through the veins, has been shown strikingly in a method formerly in vogue of treating phthisis by injections of hydrogen sulphide and carbon dioxide. In this case the gas is taken up by the veins of the portal system and excreted before it comes in contact with the arterial blood.

If a solution of blood be exposed to the air for some time it undergoes various changes, accompanied by an alteration in the absorption spectrum. This alteration can be brought about by the action of weak acids, and also of potassium permanganate, on blood. A substance called *methæmoglobin* is formed. Its absorption bands are three, nearly coincident with those seen when sulphæmoglobin is shaken with air, but one band is more completely within the limits of the red. Methæmoglobin is believed to be a highly oxidized hæmoglobin, but its constitution is in some doubt.

Many other changes in the absorption spectra of blood are known, but while the investigation of them has much to do with physiological chemistry, the matter is too technical for discussion here. It is obvious, from what has been said, that very important medico-legal, toxicological, and even clinical questions can be determined by means of the spectroscopic appearances. The different effects produced on blood by different poisonous gases and vapors, the general symptomatology of which may be the same, offer a means of determining even post mortem the character of the gas.

Clinically, the spectroscopic appearances may be utilized for examining the fluids of the body either in their normal or in their abnormal condition. The spectrum of bile, for instance, may be utilized for the detection of it in the urine, for when the color reaction is too faint to be perceived by the unassisted eye, the spectroscope will show it. Normal urine contains a coloring matter believed to be derived from a constituent of bile, which gives a broad absorption band on the green. In certain febrile affections another band appears, also in the green, toward the border of the yellow. Blood in urine may also be detected by the spectroscopic tests. If it be in solution in the urine, the absorption spectrum is seen without difficulty. If the blood be present in the form of methæmoglobin, as is sometimes the case, it will give the three bands peculiar to that body, but it is necessary to distinguish these bands from those produced by a decomposition product of hæmoglobin known as *acid hæmatin*. This distinction can be made by the use of ammonium sulphide, when, if methæmoglobin is present, the band of reduced hæmoglobin, as described above, will appear. If the blood is in the insoluble form no absorption bands may be shown. In this case the blood is filtered and the filter paper treated with alcohol and ammonia, and then with ammonium sulphide; bands then appear which are due to *reduced hæmatin* formed by decomposition.

In the accompanying map (Fig. 4340) are shown some of the important absorption spectra as seen in a refraction

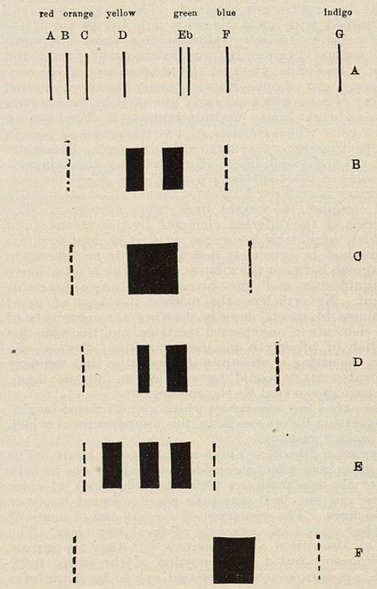

Fig. 4340.—A. Principal lines of solar spectrum as seen in a refraction spectroscope. B. Absorption bands of oxyhæmoglobin. C. Bands of reduced hæmoglobin. D. Bands of carbon monoxide hæmoglobin. E. Bands of methæmoglobin. F. Spectrum of normal urine.

spectroscope of moderate power. Over the plate has been placed indications of the limits of the various colors, but these must be regarded as a mere approximation, as it is not possible to determine precisely at what point one color ceases and another begins. The dotted lines at each end of the plates represent the limits of the visible spectrum in each case, and it will be noticed that there is considerable extinction of color, especially toward the violet end. *A* represents the spectrum of sunlight, with some of the principal absorption bands, and the letters which distinguish them. All these bands, as has been remarked above, are absent in the light of ordinary flames and electric lights. The observation of absorption spectra being made with artificial light does not therefore show any such bands. *B* shows the absorption bands of oxyhæmoglobin. The visible spectrum, it will be seen, extends only from green to a short distance on the red. *C* shows the spectrum of reduced hæmoglobin. The limits of the visible spectrum are extended slightly toward the violet. *D* is the spectrum of carbon monoxide hæmoglobin, that is, of blood impregnated with carbon monoxide. *E* is the spectrum of methæmoglobin. *F* is the spectrum seen commonly in normal urine. The broad band is at about the junction of the blue and green and is somewhat faint.

Limited practical clinical application is made of these spectroscopic appearances. The instruments required are expensive and involve delicate adjustment, and hence they are unsuited to the general uses of the practitioner. A combination of spectroscope and polariscope has been constructed for use in rapid approximate estimation of sugar in urine. The use of the spectroscope in the detection of various natural and artificial colors, and in the recognition of blood stains, belongs to special treatises.

Henry Leffmann.

SPEECH. See *Larynx, Physiology of the.*

SPERMACETI.—(*Cetaceum*, U. S. P., B. P.; Ger., *Blanc de Balsine ou Cetine;* Cod. Med., *Sperma-Ceti*). A solid paraffin-like substance obtained from cavities in the head of the sperm-whale, *Physeter macrocephalus* L. (order *Cetacea*). This whale is the largest living animal, gregarious in its habits and found in the oceans of both hemispheres, from the extreme north to the tropics. It is hunted for its oil, which is one of the most valuable of its class.

Crude spermaceti is a semisolid, yellow substance as it is scooped out from its reservoirs, but becomes hard and brittle upon exposure to cold; for purification, it is then pressed in bags, when the oil squeezes through, and the solid *cetaceum* is left behind. This can be further purified by melting in water, skimming, and recrystallization. Purified spermaceti is a pearly white, glistening, crystalline, translucent, odorless, and tasteless solid, insoluble in water; soluble in ether, chloroform, and boiling alcohol. Melting point 111° to 112° F. It is mostly composed of *palmitic* acid combined with *cetyl* (instead of glycerin); there are also small quantities of compounds of *stearic*, *myristic*, and *lauric acids*. It is fairly permanent in the atmosphere, in this respect excelling most fats.

Use.—Spermaceti has no active medicinal qualities. It is sometimes used in sore throats, etc., where its value is mostly as a protective. Its principal employment in medicine is as an ingredient of cerates and ointments, to which it gives consistence, blandness, and permanence.

There is an official cerate (*Ceratum Cetacei*) consisting of 35 parts of white wax, 10 of spermaceti, and 55 of olive oil, made by melting together the two former, adding the oil, previously heated, and stirring constantly until cold. Spermaceti is also an important constituent of ointment of rose water or cold cream (*Unguentum Aquæ Rosæ*, U. S. P.).

W. P. Bolles.

SPERMATORRHŒA. See *Sexual Organs, Male, Diseases of.*

SPERMATOZOA.—(Greek, σπέρμα, seed, and ζῶον, an animal.) A *spermatozoon* is a free, usually motile cell that is capable of uniting with an ovum to form the germ of a multicellular organism. The penetration of the ovum by the spermatozoon and the union of the nuclei of the two cells constitute the chief processes in the act of fertilization, which is the essential feature in sexual reproduction; and the ability to produce spermatozoa or their equivalent is the essential distinction of organisms of the male sex (see *Sex*). The spermatozoon is distinguished from the ovum by being vastly smaller and generally by being capable of locomotion (see *Ovum*).

Historical.—Spermatozoa were observed for the first time by Ludwig Ham, a pupil of Leeuwenhoeck, who in turn communicated the discovery to the Royal Society of London in a letter dated November, 1677. The discovery of these minute living bodies in the semen of man and a number of animals aroused great interest, especially as Malpighi a few years before (1672) had published the results of his observations on the embryology of the chick, and had concluded, in contradiction to Harvey, that the embryo is preformed in the egg. Now the question arose as to whether the moving elements of the semen might be germs which enter the eggs and develop into embryos. Leeuwenhoeck took the affirmative position and had many followers, but a greater number of the preformationists took the opposite view and held those bodies to be merely internal parasites. The name "spermatozoa" was given to them by von Baer with this idea in mind. The position of the "ovists" was strengthened by Bonnet's discovery of parthenogenesis, published in 1762 (the experiments were begun in 1740), which showed that in some cases an embryo can be formed without a male parent.

The first successful step toward a real knowledge of spermatozoa by means of experiments in artificial fertilization of ova of animals was made by Jacobi, and communicated to the Berlin Academy by Gleditsch in 1764. Jacobi placed the ripe spawn of salmon and trout in water and added seminal fluid squeezed from a male. After five weeks the eggs showed signs of life. It was apparently not these experiments, however, but some unsuccessful attempts made by Malpighi much earlier that led to the truly remarkable series of experiments by Spallanzani (1786). He wisely chose the amphibia for his material. First, he showed that eggs taken from the oviduct could be caused to develop by the addition of sperm taken from the seminal vesicles, while similar eggs not so treated failed to develop.

Second, he disproved the idea current at that time that the fertilizing element was an *aura seminalis*, a seminal vapor. This was done by causing frog's eggs to adhere to a watch glass, which was then inverted over another containing some of the sperm, and both were put in a warm place. The eggs became wet by the condensation of the vapor that was distilled from the sperm, but no fertilization took place. After some of the material in the lower watch glass had been added to the eggs, however, they speedily developed.

Third, by filtering the sperm he showed that the *liquor seminalis* has no fertilizing effect, but that the residue washed from the filter paper has undiminished power. Spallanzani was prevented from reaching correct conclusions as to the nature of the spermatozoa, however, because he accepted Bonnet and Haller's theory of the preformation of the germ in the female, the truth of which he thought he had demonstrated in the amphibia. Spallanzani produced artificial fertilization also in the eggs of silk moths and in a dog.

The next important contribution to the history of the spermatozoa is furnished by the brilliant observations and experiments of Prévost and Dumas (1824). They studied the anatomy and secretions of the reproductive organs of vertebrates of all classes above the fishes, and found that spermatozoa are produced in the testes only, and that these are the only organs essential to the fertility of the male; that spermatozoa exist in all fertile males and are absent from immature and senile individuals and from infertile hybrids; and that each species has its own peculiar form of spermatozoon. Having thus shown the close relation between the spermatozoon and its host and the correlation between the presence of spermatozoa and fertility of the male, these authors proceeded to repeat Spallanzani's experiments upon frog's eggs. They made improvements upon his methods, making the experiments more exact, and they demonstrated further that the spermatozoa are capable of penetrating the jelly surrounding the eggs. Spallanzani's results in regard to the aura seminalis and the liquor seminalis were confirmed and the important conclusion added that the spermatozoa are the essential fertilizing elements.

After all this it seems very strange to find the spermatozoa included in Owen's article on "Entozoa" in

"Todd's Cyclopædia" (vol. ii., 1836–39), and to read in Johannes Müller's "Physiology" (1840) that it is doubtful whether the spermatozoa are parasites or living parts of the animal in which they occur.

This uncertainty is due to the fact that the observations recorded heretofore lacked two essential points: they failed to show how the spermatozoa arise in the testis, and they failed to give any hint as to how the spermatozoa behave upon reaching the ovum. The first of these gaps was filled by a series of papers by Kölliker beginning in 1841, in which, besides describing the spermatozoa of a large number of species, largely invertebrate, he shows that they arise by the metamorphosis of cells in the tubules of the testis.

Although, according to J. A. Thomson, the union of spermatozoon and ovum was observed in the rabbit by Martin Barry, an Edinburgh medical student, in 1843, it really remained for

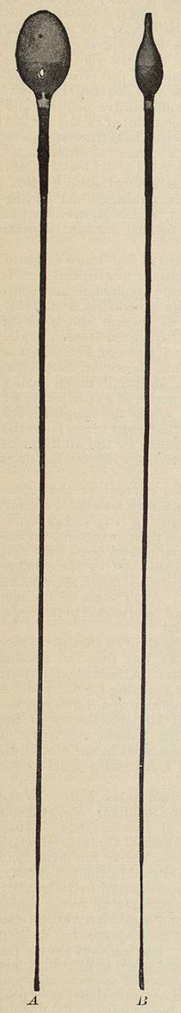

FIG. 4341.—A Typical Human Spermatozoon. *A*, View of broad side; *B*, narrow side. Both show anterior and posterior part of head; neck with inner centrosome (in two parts); middle piece, main part of tail, and end piece. There is a dark spot in anterior part of head. Magnified about 3,000 diameters. (After Retzius.)

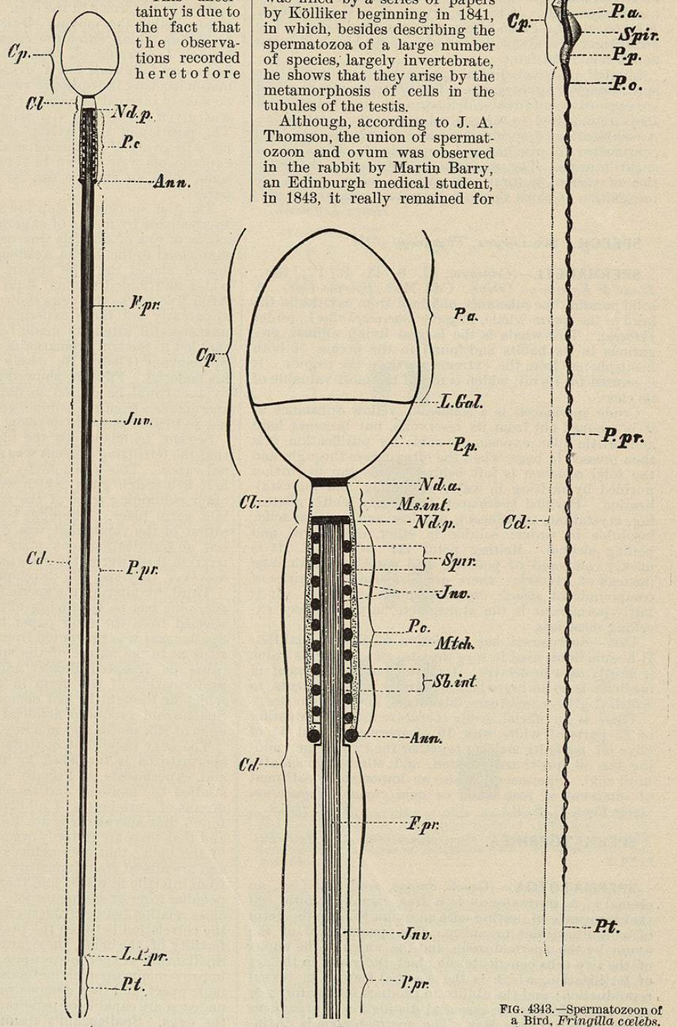

FIG. 4342.—Diagram of the Structure of the Human Spermatozoon. *A*, Whole; *B*, upper part more magnified. *Cp*, Head; *Cl*, neck; *Cd*, tail; *P.c*, middle piece; *P.pr.*, main part of tail; *Pt.*, end piece; *P.a.*, and *P.p.*, anterior and posterior parts of head; *Nd.a.*, inner centrosome; *Nd.p.*, anterior part of outer centrosome; *Ann.*, annulus; *Spir.*, spiral filament; *Mtch.*, mitochondria; *F.pr.*, axial filament; *Jnv.*, involucrum. (After Meves, from Waldeyer.)

FIG. 4343.—Spermatozoon of a Bird, *Fringilla cœlebs*. *Cp.*, Head; *Pf.*, acrosome; *P.a.*, anterior part; *P.p.*, posterior part; *Spir.*, spiral fold; *Cd.*, tail; *P.c.*, middle piece; *P.pr.*, principal part; *Pt.*, end piece. Highly magnified. (After Waldeyer.)

O. Hertwig to fill the second gap many years later (1875) from observations on starfish eggs. In this favorable material he was able to demonstrate that fertilization is effected by the entrance of one spermatozoon into the egg and the union of its nucleus with the egg nucleus. Thus two centuries, less two years, elapsed between the discovery of spermatozoa and the demonstration of the part played by them in the important function of reproduction. Even then the knowledge gained was very superficial. Much has been done during the past quarter-century toward gaining a deeper insight into the nature of the spermatozoon and the process of fertilization, but there is still an inner mystery into which our minds and our microscopes are equally unable to penetrate; and, while we may expect great progress in the future, it is probable that there will always be a limit beyond which the man of science must say, "I do not know" (see *Impregnation*).

Morphology.—There are as many forms of spermatozoa as there are species of animals. We may take as our type the spermatozoon of man, because of its intrinsic interest as well as on account of its relatively simple structure (Fig. 4341).

In the spermatozoa of vertebrates Waldeyer distinguishes three regions—the head, the neck, and the tail. The head of the human spermatozoon is flattened. The wider face is broadly oval or nearly elliptical (Fig. 4341, *A*). Viewed from the side, it is seen to be more flattened toward the apex, the proximal two-thirds being narrowly ovate (Fig. 4341, *B*). According to Meves, the head may be divided into two parts—anterior and posterior (*P.a* and *P.p.*, Fig. 4342). The anterior part is covered with a thin protoplasmic cap extending to the line *L.Gal.*, Fig. 4342, *B*. From its staining reactions and its history the head, with the exception of the cap and a thin covering membrane, is known to be composed of the cell nucleus with its chromatin contents. The neck of the human spermatozoon is inconspicuous (*Cl.*, Fig. 4342). It is in all forms a short region joining the head and tail, and containing the anterior centrosome (*Nd.a.*, Fig. 4342, *B*) and the homogeneous material connecting it with the posterior centrosome (*Nd.p.*). The tail (*Cd.*, Fig. 4342) contains three parts—the middle piece, the principal part, and the end piece (*P.c.*, *P.pr.*, and *P.t.*, Fig. 4342, *A*). Throughout the length of the tail there extends an axial filament, which has been shown by maceration to be a bundle of extremely minute fibrils. The middle piece is about as long as the head and, according to Meves, has a rather remarkable structure. At its extremities are the two parts of the outer centrosome. The axial filament has its origin in the anterior part (*Nd.p.*, Fig. 4342) and passes through the posterior part, or annulus (*Ann.*, Fig. 4342). The axial filament is surrounded by an inner sheath. Outside of this is a spiral fibre lying in a clear substance. This is covered by a finely granular protoplasmic layer, the mitochondria. The principal part of the tail consists of the axial filament and a covering, the involucrum, which is probably continuous with the inner sheath of the middle piece. The end piece consists of axial filament alone.

Human spermatozoa are small compared to those of some other mammals, as will be seen by reference to the following table made from data given by Boston (1901):

SPERMATOZOA OF	Total length.*	Head.		Tail length.
		Length.	Width.	
Man	51– 58	4– 6	3– 4	41– 53
Dog (mastiff)	67– 74	4– 8	3– 4	59– 67
Rabbit	51– 66	6– 9	3– 4	45– 58
Horse	64– 67	6– 8	3– 4	54– 60
Bull	87– 93	9	6	77– 83
Sheep	83	9•	6	74
Cat	58– 74	0– 7	3– 3	53– 66
Mouse	120–158	8– 9	3– 4	112–138
White rat	225–238	12–16	.....	209–222
Guinea-pig	113–138	6–12	7–11	102–132

* All measurements are given in thousandths of a millimetre (μ).

Some of these figures differ considerably from those given by Waldeyer (1902, pp. 158, 159), and this is probably due to there being a large amount of individual variation among the spermatozoa from a single subject as well as variation in the types of spermatozoa produced by different males of the same species. Among the vertebrates the smallest spermatozoa are found in Amphioxus, 16 to 21 μ in length according to Sobotta, while the largest are produced by a European toad, *Discoglossus pictus*, the length, according to Spengel's measurements, being 2,000 μ = 2 mm.

The various forms of spermatozoa are classified by Waldeyer into two principal groups and several subdivisions as follows:

I. Spherospermia.
  1. Without appendages.
  2. With appendages.
II. Nematospermia.
  1. Without lateral membrane.
    (*a*) Head rounded.
    (*b*) Head elongated.
  2. With lateral membrane.
    (*a*) Head rounded.
    (*b*) Head elongated.

To the first group, spherospermia without appendages, belong the simple spermatozoa of the nematoda. For example, Ascaris has a simple conical spermatozoon without appendages of any kind.

Spherospermia with appendages are characteristic of the decapod crustacea—the lobsters, crabs, and their allies. They present a great variety of form. There is generally a more or less rounded body with several or many spine-like projections.

The human spermatozoa belong to the group of nematospermia without lateral membrane and with rounded head. These have been sufficiently described above. In the simple spermatozoa of a medusa, Aurelia, we find an elongated head tipped with a sharp point, or *acrosome*. In some of the more complicated spermatozoa the head is very much elongated and the long sharp acrosome is provided with a barb like a minute harpoon. The lateral membrane is a fin-like fold lying on one side of the tail and it usually shows undulating movements. At its margin it encloses a fibre made up of fibrillæ, like the axial fibre. This form of spermatozoa is especially characteristic of the tailed amphibia.

Besides the normal spermatozoa there have been found in many species abnormal forms—giant spermatozoa, worm-like, double ones, etc. Some of these forms are clearly pathological, but in other cases there may be a normal dimorphism.

Early Development.—The course of development of spermatozoa is identical with that of the ova up to the time of the differentiation of the gonads (see *Ovum* and *Reduction Division*).

Confining our attention for the present to the vertebrates—the rudiment of the testis, like that of the ovary, is a genital ridge lying upon the Wolffian body, and continuous with the peritoneum of the upper part of the body cavity. The seminiferous tubules are formed from strands of cells that grow into the stroma from the thickened epithelium of the genital ridge. According to B. M. Allen, these strands are homologous with the medullary cords of the ovary (see *Ovum*). They subsequently acquire a lumen, and become connected with the rete tubules, which in turn connect with the vas deferens.

The young seminiferous tubules contain two kinds of cells—large, clear, spherical germ-cells, or *archispermiocytes*, with large, round, darkly staining nucleus; and between them *epithelial cells*.

There is no further change until the advent of sexual maturity; then the process of spermatogenesis begins (Fig. 4344.) The archispermiocytes divide, one daughter cell of each pair remaining deep in the epithelium as a reserve germ cell (*spg. r*, Fig. 4345), while the other changes somewhat in appearance and becomes a *spermatogonium*. The spermatogonia divide a number of times (*spgm.*, Fig. 4345) and finally produce a generation of

primary spermatocytes (*spc.a*, Fig. 4345). These pass through the characteristic stages of synapsis and growth (*spc.g.* and *spc.i.*, Figs. 4346 and 4347). Finally, each

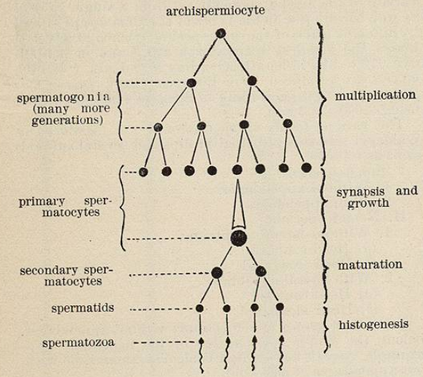

FIG. 4344.—Diagram showing the Genesis of the Spermatozoa. (Modified from Boveri.)

primary spermatocyte divides to form two secondary spermatocytes, and each of these in turn divides, giving rise to two spermatids (*spd*, Fig. 4345). During the divisions the process of maturation takes place (see *Reduction Division*).

In the mean time the epithelial cells have been undergoing a transformation into the peculiar "*cellule ramifiée*" first observed by Sertoli in 1865. The cytoplasm of these cells is naked and extends in amœboid fashion among the germ-cells toward the lumen of the tubule. After the last maturation division the spermatids (*spd*, Fig. 4345) become united with the protoplasmic processes of the Sertoli cells (*symphoresis*, Waldeyer), and remain in this connection throughout the period of histogenesis. When the spermatozoa are fully developed they are released, and the Sertoli cell becomes connected with a new set of spermatids (Fig. 4345).

This peculiar condition in the vertebrate testis has caused much confusion in the past and has led to erroneous theories as to the nature of the spermatozoa. Although Sertoli regarded the cells which bear his name as nutritive cells, von Ebner in 1871 called them "spermatoblasts" and regarded them as directly concerned in the production of spermatozoa. In this view von Ebner had many followers. The correct theory was advanced by H. H. Brown in 1885 and by Benda in 1887, and in 1888 von Ebner corrected his error and added much to the knowledge of the Sertoli cells.

Another cause of confusion in the study of spermatogenesis in the vertebrates is that before one cycle of development is completed in any part of a seminiferous tubule another begins. In the bull the spermatogenesis is a continuous process and in sections of the testis of an adult individual four stages will be found in the wall of each tubule (Figs. 4345 to 4347), but in order to follow the consecutive stages a number of sections must be examined.

The nuclear changes leading to the formation of the spermatids have been described sufficiently in another article (*Reduction Division*), and we will pass directly to the consideration of the process by which the spermatid becomes a spermatozoon, confining our attention entirely to the vertebrates and making the description as general as possible.

Histogenesis.—After the division of the secondary spermatocyte the nucleus of the young spermatid acquires a nuclear membrane and passes into the resting condition with a chromatin reticulum. The centrosome moves from its original position and divides into two, either completely or incompletely, forming a minute dumb-bell-shaped structure. In its new position the outer part lies close against the cell wall, while the inner part is directed toward the nucleus. The "sphere" of denser protoplasm that collects around the centrosome after earlier cell divisions now forms independently of the centrosomes and is called the *idiosome* (*s*, Fig. 4348).

The fate of the various parts of the cell in the development of the spermatozoon is summarized by Waldeyer as follows: Out of the chromatin of the nucleus is developed the head of the spermatozoon; a part of the idiosome forms the acrosome; the centrosome takes part in the formation of the neck, the middle piece, and

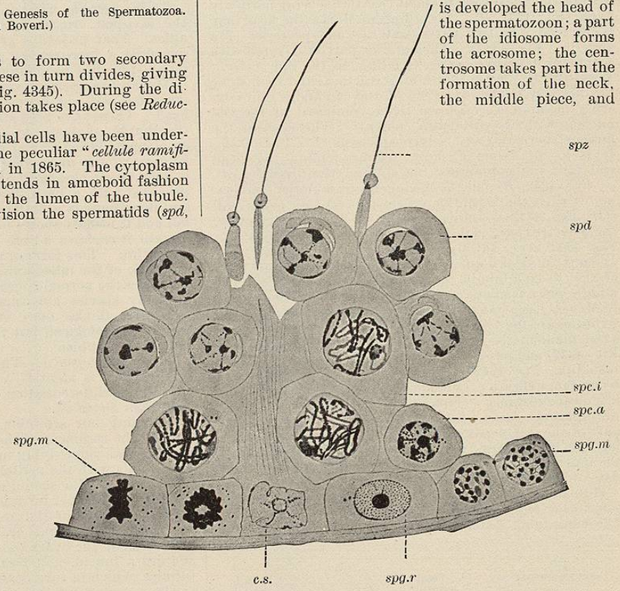

FIG. 4345.—Part of Section of Testis of a Bull, showing Stages in Spermatogenesis. *c.s.*, Sertoli cell; *spg.r.*, reserve spermatogonium; *spg.m*, spermatogonia in mitosis; *spc.a.*, first stage in development of spermatocyte; *spc.i*, spermatocyte in later stage; *spd*, newly formed spermatid just after the last maturation division; *spz*, nearly ripe spermatozoon, separated from Sertoli cell. Highly magnified. (After Schoenfeld.)

the axial filament; the cytoplasm gives rise chiefly to the axial filament, its mitochondria forms the spiral structures, and it takes part in the formation of the envelope of the tail.

The nucleus first moves from its originally central

position to the periphery of the cell opposite the centrosomes. Its chromatin network becomes gradually finer and more condensed until it forms an apparently homogeneous mass; at the same time the nucleus becomes smaller and gradually assumes its definitive shape.

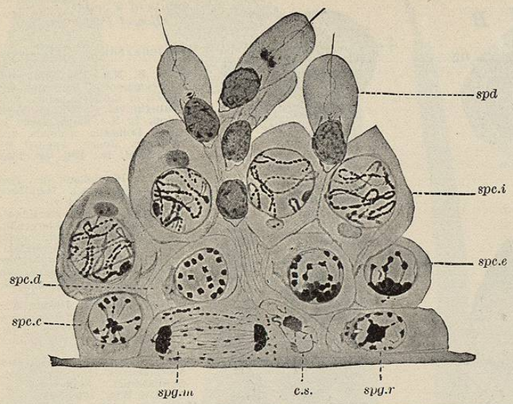

FIG. 4346.—Another Section of the Testis of a Bull. *spg.m*, Reserve spermatogonium in mitosis; *spc.c*, *d*, and *e*, spermatocytes in stages preliminary to synapsis; *spc. i*, advanced primary spermatocyte, growth nearly completed; *spd*, spermatid attached to Sertoli cell (*c.s.*) and undergoing histogenesis. Highly magnified. (After Schoenfeld.)

In the mean time a part of the idiosome, often containing a vacuole, becomes attached to the nuclear membrane and moves around the nucleus to take its position at the apex and becomes the acrosome (Figs. 4348 and 4350).

The outer centrosome becomes disc-shaped, and at a very early stage there grows out from the centre of the disc, or in close connection with it, a very fine filament, the rudiment of the axial filament of the tail (*ax*, Fig. 4348). The development of the tail, as remarked by von Ebner, is one of the most difficult problems of histogenesis. It is described variously by different authors for the same or closely related forms, and the course of development appears to differ considerably in the two groups of vertebrates in which it has been most carefully studied—the amphibia and the mammals. All agree, however, that very soon the periphery of the outer centrosome becomes separated from the axial filament and forms a ring surrounding it. In the amphibia (Fig. 4350) the axial filament appears to remain connected with the inner centrosome, while in the mammalia (Fig. 4348) the inner centrosome is free and the central part of the outer centrosome forms the end knob of the axial filament. In the mean time the whole apparatus has been moving toward the nucleus. The inner centrosome becomes attached to the nucleus and marks the position of the future neck. The central part of the outer centrosome with the axial filament follows, but in the mammals does not quite reach the same point, while the ring remains at or near the cell wall. The axial filament has been growing meanwhile and now consists of two parts, one within the cell and the other outside. The intracellular part will form the axis of the middle piece, and the outer part, the axis of the main part and the end piece of the tail. The material for the growth of the filament is probably furnished by the cytoplasm. The fate of the ring centrosome differs in the two groups. In the mammalia it remains intact and becomes the annulus at the distal end of the middle piece (Fig. 4349). In the amphibia part of it stretches out along the axial filament and gives rise in connection with the cytoplasm to the envelope of the main part of the tail. In the mammalia this part of the tail appears to be formed by differentiation of the surface of the axial filament.

As the spermatozoon begins to take shape the main part of the cytoplasm draws backward, leaving only a thin membrane on the head, and the mass of cytoplasm lies in the position of the middle piece (*cy*, Fig. 4349). Scattered thickly through the cytoplasm are fine granules with characteristic staining qualities, the mitochondria, supposed to have been furnished by the Sertoli cell. The spiral filament is formed by the concentration and fusion of this material.

In the mammalia and some other forms there is more cytoplasm than can be used in the development of the spermatozoon. This part begins to undergo degenerative changes, and at the same time is gradually constricted off from the middle piece (*cy*, Fig. 4349 *F*). The cytoplasmic remnants may remain attached to the Sertoli cell for a time after the spermatozoa have moved away.

After leaving the testis the spermatozoa undergo a further "ripen-

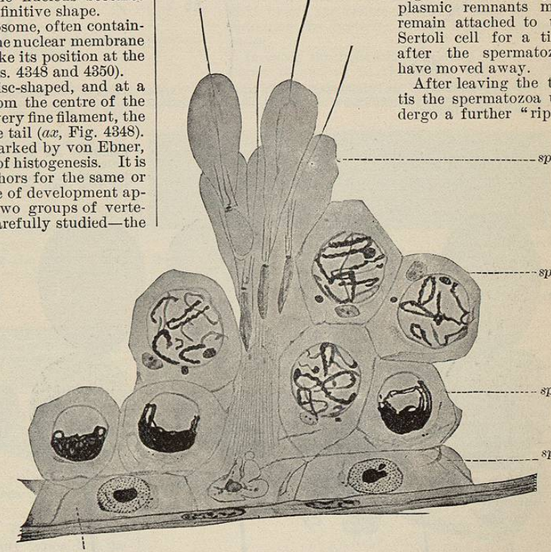

FIG. 4347.—Later Stages in Spermatogenesis of the Bull. *spg.r*, Reserve spermatogonium; *spg*, spermatogonium; *spc.g*, spermatocyte in late synapsis stage; *spc.i*, spermacyte in stage just preceding the maturation divisions; *spd*, spermatids in advanced stage of histogenesis, with heads deeply embedded in Sertoli cell. Highly magnified. (After Schoenfeld.)

ing" process, which consists chiefly in the completion of the outer envelope of the middle piece and the smoothing off of any projections or irregularities that may have remained after separation from the Sertoli cells.

It will be seen from this brief review of the development of spermatozoa that there can be no further question as to the character of these bodies. Each one contains all the essential elements of a cell.

Robert Payne Bigelow.

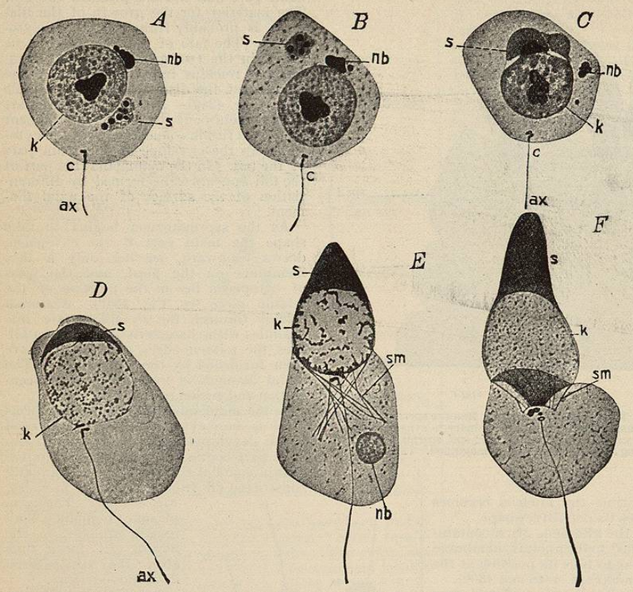

FIG. 4348.—Spermatids of the Guinea-pig, *Cavia cobaya*, in Various Stages of Metamorphosis. *k*, Nucleus; *s*, sphere; *c*, centrosome; *ax*, axial filament. Highly magnified. (After Meves, from Korschelt and Heider.)

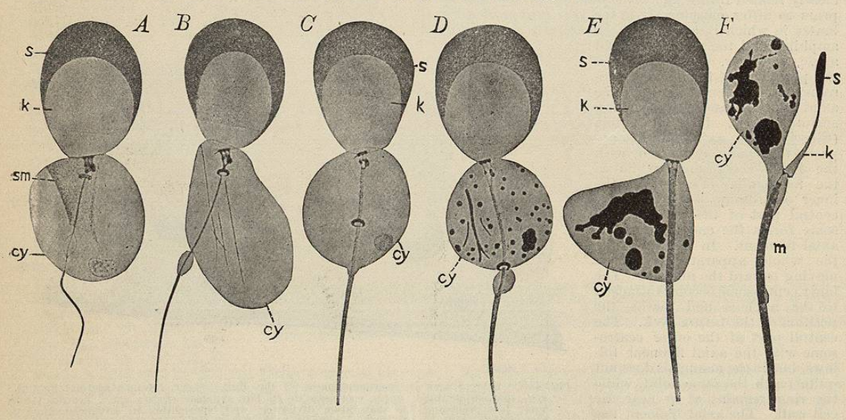

FIG. 4349.—Later Stages in the Metamorphosis of the Spermatids of the Guinea-pig. *A*—*E*, views of broad side; *F*, narrow side. *cy*, Cytoplasm; *m*, middle piece. Other lettering same as in Fig. 4348. Highly magnified. (After Meves, from Korschelt and Heider.)

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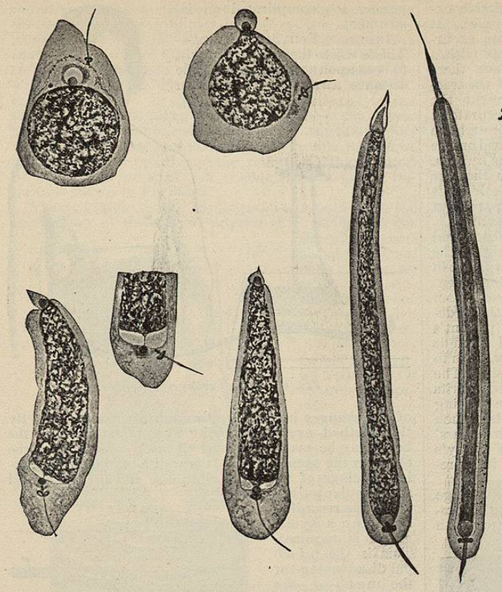

FIG. 4350.—Various Stages in the Metamorphosis of the Spermatids of Amphiuma. Highly magnified. (After McGregor.)

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SPHACELUS. See *Gangrene.*

SPHYGMOGRAPHY.—Sphygmography (Gr., *σφυγμός*, the pulse; *γράφειν*, to write), strictly interpreted, is the art of taking pulse tracings. The present article will deal not only with the art of recording the arterial and the venous pulse, but also with the graphic method as applied to the heart (cardiography). The instruments employed for these purposes are of many types, but the principles involved can be made sufficiently clear by a few examples. Two essentials are common to all of them, a recording surface and a writing lever or pen. The recording surface is usually smoked paper set in motion by clock-work. The writing lever may be directly applied to the pulse or connected with it by a rigid or jointed support, in which case we speak of *direct sphygmography*; or the movements to be recorded may be carried to the lever by air transmission, constituting *indirect sphygmography*.

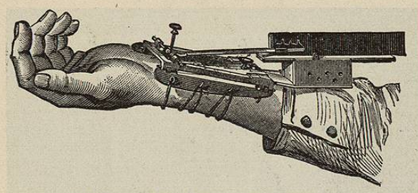

FIG. 4351.—Marey's Sphygmograph (new form).

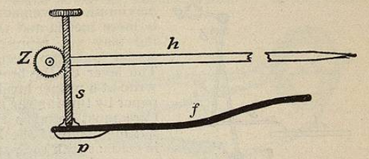

FIG. 4352.—Diagram of Connections in Marey's Sphygmograph.

DIRECT SPHYGMOGRAPHY.—Two examples of direct sphygmography will be given as represented in the instruments of Marey and of Dudgeon.

In *Marey's sphygmograph* (Figs. 4351 and 4352) the button *p* is pressed down upon the artery by the spring *f*. The screw *s* is connected with the button by a joint and rests against a cog-wheel *Z*, which is on the axis of the writing lever *h*. The thread of the screw catches in the teeth of the cog-wheel so that when the button is lifted by the pulse it raises the screw so as to turn the wheel and elevate the lever. At one end of the instrument there is a clock-work which moves a metal frame carrying a strip of smoked paper. The screw, which may be seen in Fig. 4351 under the centre of the writing lever, regulates the pressure of the button on the pulse.

In using the instrument, a strip of smooth paper is cut to fit the frame and smoked over a piece of burning camphor, a lamp burning without a chimney, or a tallow candle. The position of the radial artery is determined and the point where the pulsation is best felt is noted. The instrument is then bound to the arm, as shown in the figure, with the button on the point selected. The clock-work is wound up. The pressure of the button is regulated by the

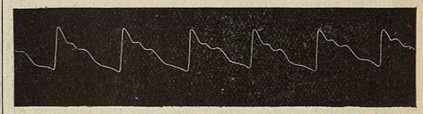

FIG. 4353.—Sphygmogram taken with Marey's Sphygmograph.

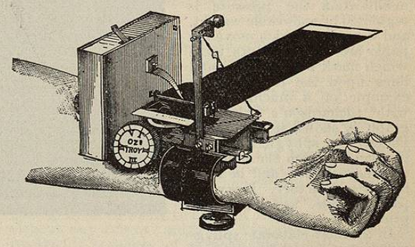

FIG. 4354.—Dudgeon's Sphygmograph.