while an imperfect layer of radially arranged bundles stretching from the sphincter to the pectinate ligament constitutes the *dilatator pupillæ*. The long controversy regarding the existence of these fibres, which are very difficult to demonstrate in the pigmented iris, may now

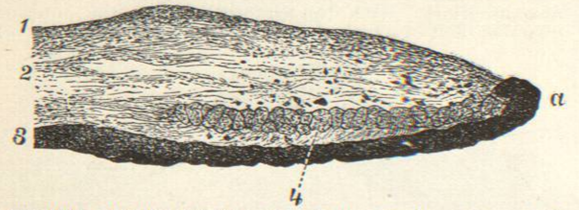

Fig. 1999.—Meridional Section through the Pupillary Zone of the Human Iris. *a*, Pupillary border formed of epithelium, arranged in bead-like processes; 1, anterior limiting layer; 2, stroma or vascular layer; 3, pigmented epithelium, continuous behind with the retina; 4, sphincter pupillæ.

be regarded as settled. The sphincter appears to be controlled by the oculo-motor nerve, the dilatator by the sympathetic.

The posterior boundary layer is a continuation of the basilar lamina of the choroid and like it is a very thin structureless membrane formed by condensation of the connective tissue of the stroma.

The epithelium of the retinal portion of the iris is in two layers, of which the outer is composed of fusiform cells, the inner of columnar cells. Both of these are densely crowded with pigment.

A vascular network, the greater arterial circle (Fig. 2003), formed by branches of the anterior and long ciliary arteries, lies at the ciliary border of the iris between the two portions of the ciliary muscle. From this arterioles pass radially toward the pupil and on reaching the sphinc-

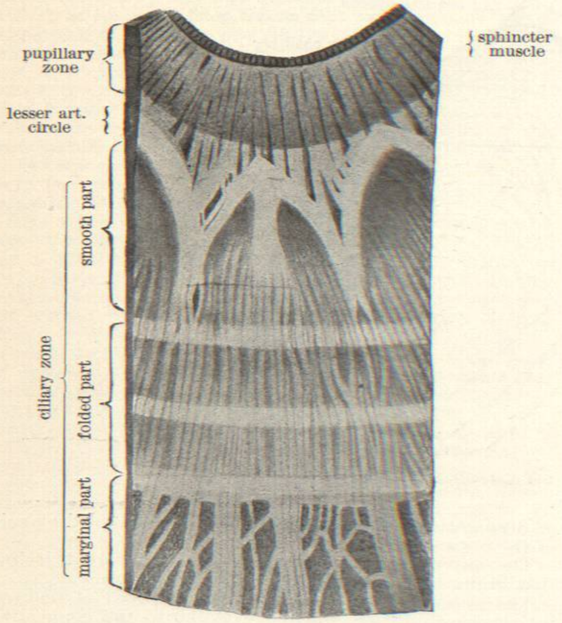

Fig. 2000.—Segment of Anterior Surface of Iris with Pupil Contracted. × 20. (Fuchs.)

ter unite in another anastomosis, the lesser arterial circle, from which are given off vessels that supply the pupillary zone and the pupillary membrane of fœtal life.

Venules from these networks pass radially outward and finally discharge into trunks that reach the vorticose veins.

There are abundant lymph spaces within the stroma of the iris, but no lymphatic vessels properly speaking.

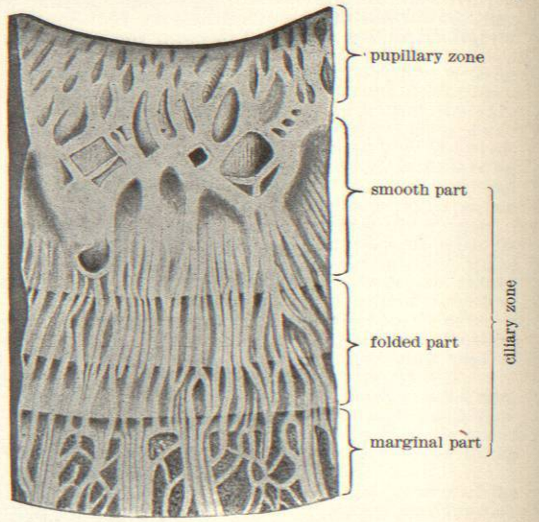

Fig. 2001.—Segment of Anterior Surface of Iris with Pupil Dilated. × 20. (Fuchs.)

The nerves of the iris are derived from the ciliary plexus. Their fibres, as they proceed toward the pupillary border, form a coarse meshwork from which are derived motor nerves with ultimate filaments that supply muscle cells, vaso-motor nerves, and sensory nerves that lie immediately under the anterior endothelium.

The Inner or Nervous Coat.—Being formed from the duplicate, invaginated layers of the optic cup, originally an outgrowth from the brain, the structure of this coat bears some analogy to that of the cerebral cortex. As the ventricles of the brain are lined with epithelium (ependyma), so the lining of the cavity of the optic vesicle, originally continuous with them, retains an epithelial character. By the invagination of the optic cup this cavity becomes obliterated, but the boundary lining remains as the two outer layers of the retina. The outermost of these is a single layer of highly pigmented epithelium; the inner one becomes, for a region extending from the optic-nerve entrance to the ora serrata, a highly specialized neuro-epithelium reinforced by a large number of nervous elements, while over the ciliary region and the iris it too

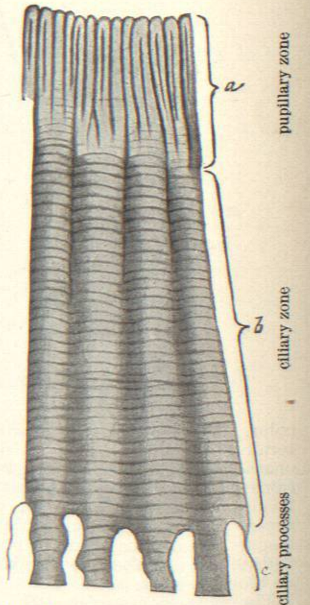

Fig. 2002.—Segment of Posterior Surface of Iris, Medium Dilatation of Pupil. × 25. (Fuchs.)

is reduced to a single layer of simple epithelium, nonpigmented in the former, pigmented in the latter region.

We may therefore distinguish three retinal regions: (1) The retina proper, or percipient retina; (2) the ciliary retina; and (3) the iridian retina. The last has already been described.

The Retina Proper is a smooth tunic that covers the posterior two-thirds of the interior of the eyeball, reaching to about 5 mm. from the attachment of the iris. When the interior of the eye is viewed by the ophthalmoscope it appears reddish from the blood-vessels that ramify in the innermost layers. Its thickness varies from 0.4 mm. behind to half that near the ora serrata. Its outer epithelial layer is deeply pigmented, the remainder perfectly transparent unless deprived of light, when it assumes a purplish hue due to a diffused coloring matter known as the visual purple. Its transparency ceases after death and sometimes during life from pathological causes. It is also normally obscured where the fibres of the optic nerve enter—the *optic disc*, and in an elliptical area lying in the optical axis—the *yellow spot*.

The optic disc (optic papilla, porus opticus), situated 1 mm. below the horizontal meridian and 3 mm. to the nasal side of the vertical meridian, is nearly circular in form with a diameter of from 1.4 to 1.7 mm. As the optic fibres pass through the lamina cribrosa they

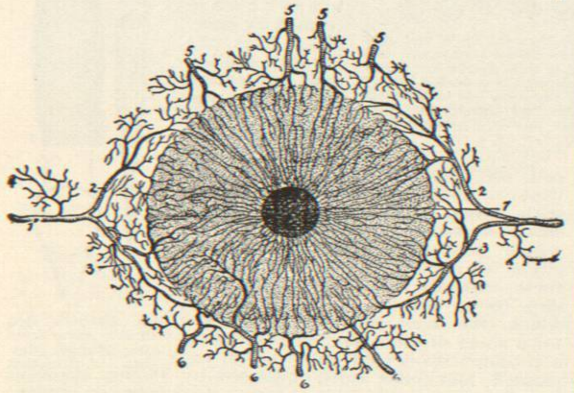

Fig. 2003.—Arteries of the Iris. (Sappey.) 1, 1, long posterior ciliary arteries; 2, 3, their branches of bifurcation; 4, recurrent arteries destined for the choroid; 5, 5, 6, 6, anterior ciliary arteries anastomosing with the long ciliary to form the greater arterial circle of the iris; 7, the lesser arterial circle of the iris.

lose their medullary sheaths and diverge, causing a depression near the centre of the disc, termed the *excavation*. The myelin of the deep fibres shining through its transparent surface gives a whitish appearance to the disc and the free edges of the sclera and choroid are seen as boundary rings. The central artery of the retina entering at the excavation ramifies upon its surface. There being no percipient elements in this area it is insensible to light, and is hence sometimes called the punctum cæcum or blind spot.

The yellow spot (macula lutea, spot of Sömmering) is a reddish-brown area nearly circular in form, about 2 mm. in diameter. Near its centre it has a depression termed the central fovea (fovea centralis), 0.02 to 0.4 mm. in diameter, which is the seat of the most acute vision. The percipient elements have here a special arrangement which will be hereafter explained.

The retina being the only sense organ directly derived from the cerebral cortex, shows combined within it structures usually widely separated. Its cells are arranged in three layers that communicate with each other in a chain-like series: (1) collective, comprising the neuro-epithelium of the rods and cones that receive the primary impulses leading to vision; (2) transmittive, bipolar cells sometimes collectively called the ganglion of the retina; (3) liminal, large multipolar cells lying near the inner surface of the retina and sending fibres brainward through the optic nerve.

Similar members exist in other sense organs; thus, in the organs of common sensation we have: (1) the epithe-

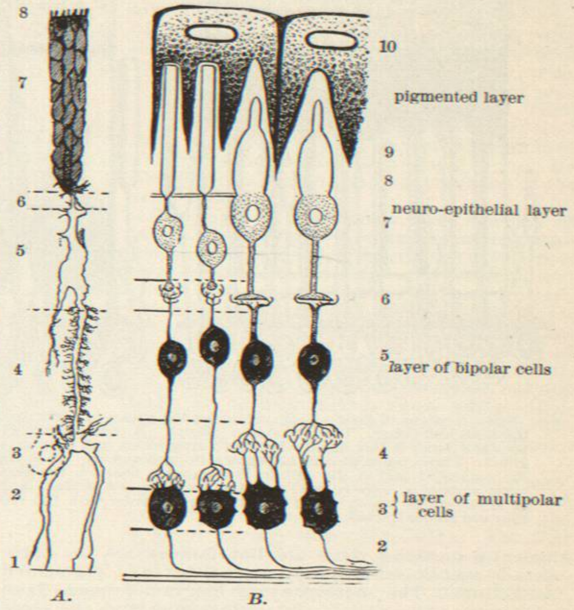

Fig. 2004.—Schema Showing the Arrangement of the Structural Elements of the Retina. A, Fibre of Müller; B, nerve and epithelial cells. 1, Membrana limitans interna; 2, layer of nerve fibres; 3, ganglionic layer, 4, inner molecular layer; 5, inner nuclear layer; 6, outer molecular layer; 7, outer nuclear layer; 8, membrana limitans externa; 9, layer of rods and cones; 10, pigmentary layer.

lium surrounding the nerve terminal in the skin; (2) the cells of the spinal ganglia, conveying the impulses to the nervous centres; (3) the cells of the receptive nuclei in the spinal cord or the medulla oblongata.

Besides the elements of the retina already mentioned, which are doubtless the main apparatus by which visual sensations are conveyed, there are certain associative cells that probably serve to correlate and co-ordinate the action of the separate neural chains.

All these may be considered active elements. There are also, in the central nervous system, certain passive

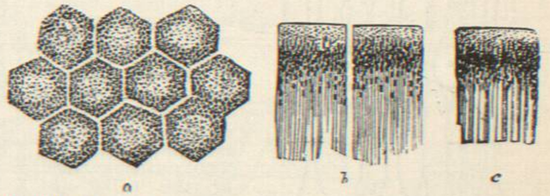

Fig. 2005.—Cells of Pigment Epithelium from the Human Retina. (Max Schultze.) *a*, Surface view; *b*, side view showing fringe-like processes that extend toward the layer of rods and cones; *c*, a cell to which the outer portions of some rods are attached.

or sustentacular elements. These, known in other regions as neuroglia cells, are in the retina called the fibres of Müller.

The retina is often described as consisting of from nine to eleven layers. There seems to be no good reason for this, as some of the appearances described as layers are caused by the intermingling processes of cells, while others, the so-called limiting membranes, are expansions from the supporting cells or fibres of Müller. Morpho-

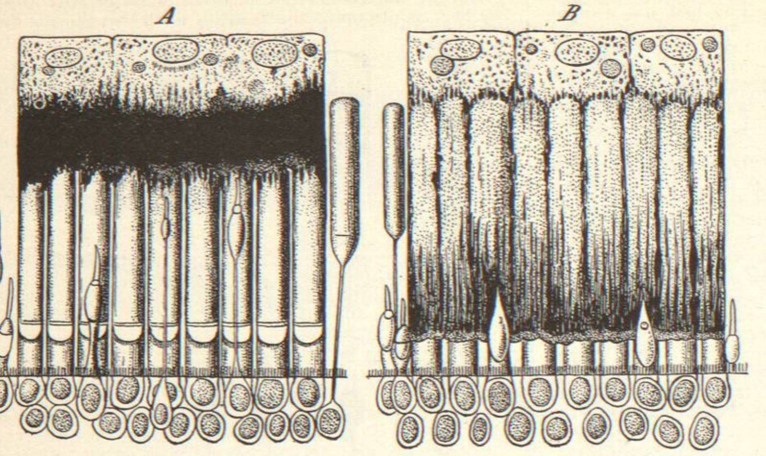

FIG. 2006.—Sections of Frog's Retina Showing the Action of Light upon the Pigment Cells, and upon the Rods and Cones. (von Gendesen—Stort). *A*, From a frog which had been kept in the dark for some hours before death; *B*, from a frog which had been exposed to light just before being killed. Three pigment cells are shown in each section. In *A* the pigment is collected toward the nucleated part of the cell, in *B* it extends nearly to the basis of the rods. In *A* the rods, outer segments, were colored red (the detached one green), in *B* they had become bleached. In *A* the cones, which in the frog are much smaller than the rods, are mostly elongated, in *B* they are all contracted.

logically speaking there are but four layers, the three already mentioned and the external layer of pigmented epithelium. The accompanying diagram presents both the older and the more recent nomenclature (Fig. 2004). The layers will be described in succession from without inward.

The pigmented layer comprises the entire outer lamella of the optic cup, the part not invaginated in the course of its development, and is composed of a single layer of tesselated polygonal cells (Fig. 2005), whose protoplasm is crowded with colored granules (the fuscin of Kühne), which have the form of minute crystals with long axes perpendicular to the retinal surface. They are somewhat more deeply colored near the ora serrata. The outer surface of the cells, applied to the basilar lamina of the choroid, is smooth and devoid of pigment; the inner surface is not well defined, for it consists of fringe-like filaments loaded with pigment that extend down between the outer segments of the

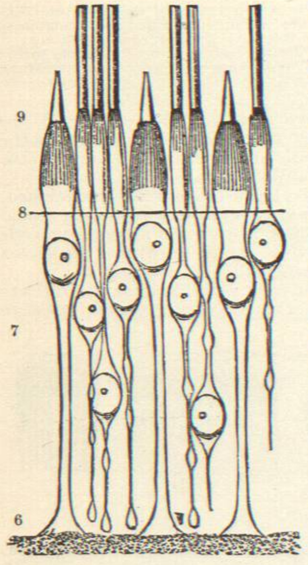

FIG. 2007.—Neuro-epithelium of the Human Retina. (Max Schultze.) 6, Arborescent processes, forming the appearance known as the "external molecular layer"; 7, nuclei of the epithelial cells, forming the "external nuclear layer"; 8, grillwork formed by processes of the fibres of Müller, forming the "membrana limitans externa"; 9, specialized processes of the epithelium, forming the layer of rods and cones.

rods and cones which are applied directly against it. Experiments have shown that the distribution of the coloring matter in these cells varies with exposure to light, for during prolonged darkness it is withdrawn into the cell bodies, while after the stimulus of light it descends like a curtain into the fringe between the rods and cones (Fig. 2006). The visual purple found in the outer segments of the rods appears to be derived from the pigmented layer.

The neuro-epithelial layer, or layer of visual cells proper, comprises two distinct elements, the rod cells and the cone cells (Fig. 2007), set in a framework (external limiting membrane) formed by processes from the fibres of Müller, and projecting into the pigmented fringe already described. These cells are bipolar in form, having elliptical cell bodies (rod and cone granules) with large nuclei surrounded by a small amount of protoplasm from which processes extend radially in either direction. The outer one of these expands into the peculiar bacillary forms known as the rods and cones; the inner one extends inward for a short distance and ends either in a rounded knob (rod cells) or an expanded foot (cone cells) embraced by the filamentous terminals of the ganglion cells of the next layer.

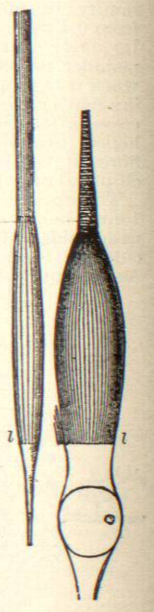

FIG. 2008.—A Rod and a Cone from the Human Retina. *l*, Situation of the membrana limitans externa.

The bodies of the rod cells, which lie at various levels, show when stained under favorable conditions dark and light bands. The rods themselves are divided into two nearly equal segments: an outer, cuticular, doubly refracting one, and an inner, protoplasmic singly refracting one; the former being cylindrical, staining but slightly

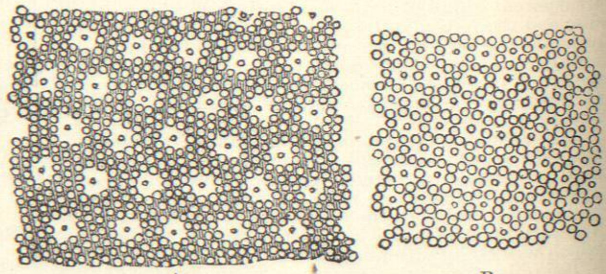

FIG. 2009.—Distribution of the Rods and Cones. *A*, From the peripheral portion of the retina; *B*, from the region of the macula lutea.

and having a tendency to break up into superimposed discs; the latter slightly elliptical in outline, staining readily and showing at its outer end a fibrillated area called the ellipsoid, more apparent in the lower animals

than in man (Fig. 2008). The outer segments are purplish-red in tint, owing to the diffusion through them of *visual purple* or rhodopsin, the peculiar coloring matter of the retina, which quickly bleaches in the presence of light.

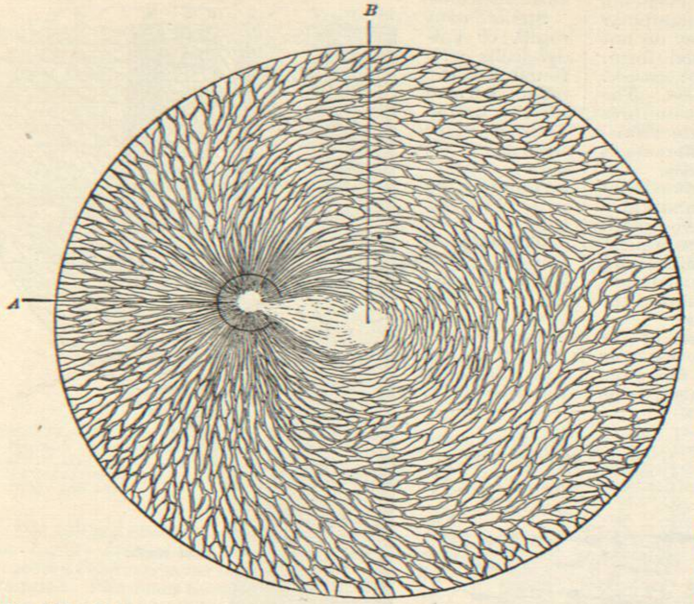

FIG. 2010.—Radiation of the Optic Nerve Fibres upon the Retina. (Michel.) *A*, Optic disc; *B*, macula lutea.

The bodies of the cone cells (Fig. 2007) are contiguous to their bacillary processes or cones. The latter also have an outer and an inner segment. The outer segment, apparently similar in intimate structure to that of the rods, is, however, much shorter, ending in a blunt point. The inner one, thick and flask-shaped, contains also an ellipsoid. During prolonged darkness the cones appear to stretch outward toward the pigmented layer (Fig. 2006). They do not contain rhodopsin.

The distribution of the rods and cones varies in different parts of the retina and in different animals (Fig. 2009). In the central fovea, the region of the most acute vision, cones only are found, but from this point forward the proportion of rods gradually increases, until at the ora serrata cones are almost wholly absent. It is estimated by Krause that there are in the retina about seven million cones, or seven to each fibre of the optic nerve, and that the number of rods is about 130,000,000. While in fishes the rods far exceed the cones in number, in birds and reptiles the reverse is the case, lizards possessing cones alone.

In the layer of bipolar cells the characteristic elements are fusiform with protoplasmic processes that surround the inner terminals of the visual cells. They may therefore be distinguished as rod bipolars and cone bipolars according as they are related to the rod or to the cone cells. The rod bipolars have protoplasmic processes with vertical arborizations, embracing from three to twenty bases of rod cells, and long axis-cylinder processes that penetrate centrally as far as the bodies of the multipolar cells, around which they ramify. The cone bipolars have protoplasmic processes, with horizontal arborizations that interblend with twigs from the feet of several cone cells, probably including also in their contact area some of the terminations of the rods. Their axis-cylinder processes are much shorter than those of the rod bipolars and terminate on five different and quite determinate levels by blending with the ascending processes of the cells of the next layer.

The layer of multipolar cells consists of large, irregularly oval elements with protoplasmic processes that intertwine with arborescences of cells from the outer layers, and whose axis-cylinder processes turn toward the optic disc and become fibres of the optic nerve (Fig. 2010). The cells of this layer are classified according to the arrangement of their protoplasmic processes: (1) monostratified, those whose processes ramify in but one level; (2) multistratified, those whose processes ramify in more than one level; (3) diffuse, those whose protoplasmic arborescences are not limited to definite levels.

At two different levels of the retina associative cells are found: (1) in relation to the rod and cone cells; (2) in relation to the layer of bipolar cells (Fig. 2011). The first class run parallel to the layers of the retina and hence are often called *horizontal* cells, three varieties of which are distinguished: one small, flattened, stellate, *cone associatives*, connecting cone-terminals with each other; another larger and placed somewhat deeper, *rod associatives*, connecting by means of long axis-cylinder processes rod terminals; a third, large, pyriform in shape, having descending processes that pass centralward as far as the internal ramifications of the bipolar cells.

The second class of associative cells is situated in the internal portion of the layer of bipolar cells, constituting there what some authors recognize as a distinct layer of the retina. W. Müller, supposing them to be of a sus-

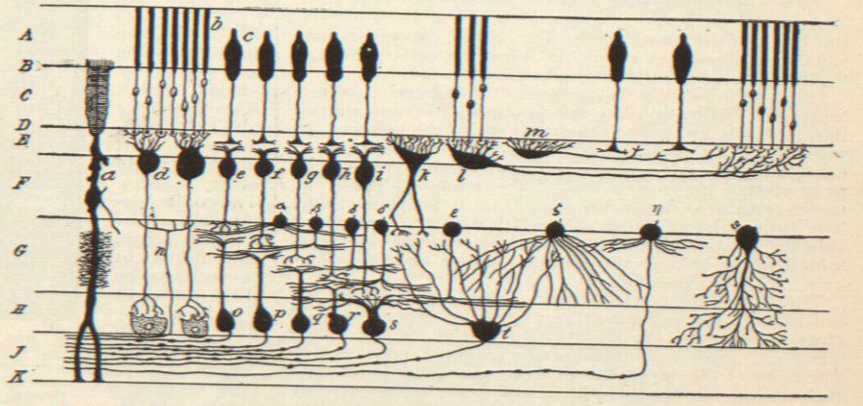

FIG. 2011.—Diagram Illustrating the Relation of the Retinal Elements. (Kallius.) *A*, Layer of rods and cones; *B*, limitans externa; *C*, outer nuclear layer (bodies of visual cells); *D*, Henle's external fibrous layer (composed principally of rod fibres); *E*, outer plexiform layer; *F*, inner nuclear layer (rod and cone bipolars); *G*, inner plexiform layer; *H*, layer of large ganglion cells; *J*, fibre layer; *K*, limitans interna; *a*, supporting fibre of Müller; *b*, *c*, rod and cone visual cells; *d*, bipolars belonging to rod cells; *e–i*, bipolars belonging to cone cells; *k–m*, horizontal nerve cells; *n*, centrifugal nerve fibre; *o–t*, ganglion cells connected with optic fibres; *α–ε*, amacrines arranged in layers; *ζ–ϑ*, diffuse amacrines; *η*, nervous amacrine.

tentacular character, called them spongioblasts. It seems desirable to discontinue the use of this name as it has been applied by His to totally different structures, the primitive cells of the medullary plate from which neuroglia is formed. Ranvier, who regarded these elements as undoubtedly nervous, designated them as unipolar cells. Cajal, having in view the fact that they do not show any axis-cylinder process of the typical form, called them *amacrine* cells, from *a*, privitive; *μακρός*, long; *ἴς, ἰνός*, nerve—*i.e.*, having no long process. The name is not wholly satisfactory, as homologous structures in reptiles and birds undoubtedly possess a distinct axis-cylinder process, and in man a considerable difference is noted in the ramifications on two sides of the cells.

These cells are large and pyriform with arborescent processes extending inward, and may be subdivided into *diffuse* amacrines that send ramifications throughout all levels where the terminals of the bipolars branch, and *stratiform* amacrines that confine their ramifications to one of the five levels at which the cone bipolars terminate. Their terminal filaments appear to embrace the inosculations of the bipolar and multipolar cells.

It will be remembered that the greater part of the fibres of the optic nerve originate as outgrowths from the cells of the retina. Some "centrifugal" fibres do, however, occur, probably for conveying impulses from the brain to the retinal cells (Fig. 2012). Some of these end by ramifications about the amacrine cells, others at various levels by horizontal arborescence.

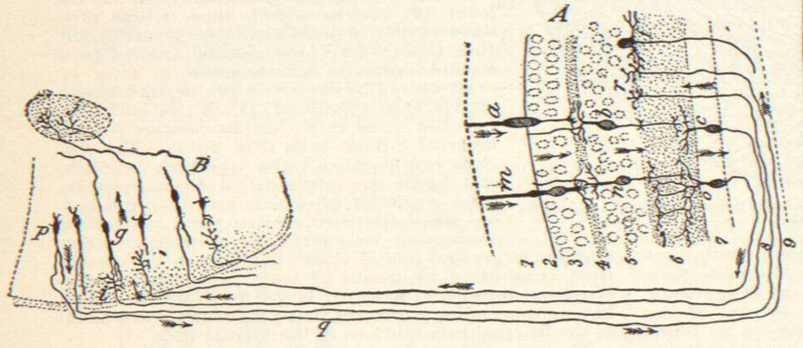

FIG. 2012.—The Course of Nerve Fibres Between Retina and Brain. (Ramon y Cajal.) *A*, Retina; *B*, corpus geniculatum; *j*, central ganglion; *a*, *b*, *c*, a cone system composed of a rod, a bipolar cell, and a multipolar cell; *m*, *n*, *o*, a rod system composed of a rod, a bipolar cell, and a multipolar cell; *g*, cells of the corpus geniculatum that receive excitations from the retina through the optic nerve; *p*, *q*, *r*, a centrifugal current originating in the brain and passing to the retina.

During the early development of the neural tube certain cells, called by His spongioblasts, become shaped into rods extending throughout the entire thickness of the wall of the tube and constituting, by interlacing processes, an efficient framework for supporting the delicate protoplasmic nerve cells that they surround. These elements remain as the neuroglia of adult nervous tissue. The retina shows its genetic relation to the medullary tube by the possession of similar sustentacular elements which are known as the *fibres of Müller* and the *spider cells*.

The fibres (Fig. 2011) extend radially throughout all portions of the percipient retina, being especially well marked near the ora serrata and in the macula lutea. They are greatly modified and elongated cells, whose nuclei lie at the level of the layer of bipolar cells. At the internal surface of the retina they commence by broad and often forked bases that unite with each other to form a continuous boundary known as the *internal limiting membrane*, which, however, cannot in any way be considered to be an independent structure. At their distal or external ends they unite to form a grillwork around the rods and cones which project beyond them. This fenestrated structure is inaptly called the *external limiting membrane*. Septa from the fibres closely invest the bodies of the visual cells, and delicate lateral processes are also given off by them for the support of the terminals of the bipolar, multipolar, and amacrine cells.

Stellate neuroglia or spider cells are found near the inner surface of the retina between the bundles of nerve fibres and among the multipolar cells.

The structure of the retina in the macula lutea and fovea centralis varies somewhat from that already described (Fig. 2013). In the fovea the cones are the only visual cells found, being there much narrower and longer than in other regions. The conical depression of the fovea causes the fibres of the cells to be drawn out obliquely. The bipolar and multipolar layers disappear at the centre of the fovea, but immediately about it, within the macula, become increased in thickness.

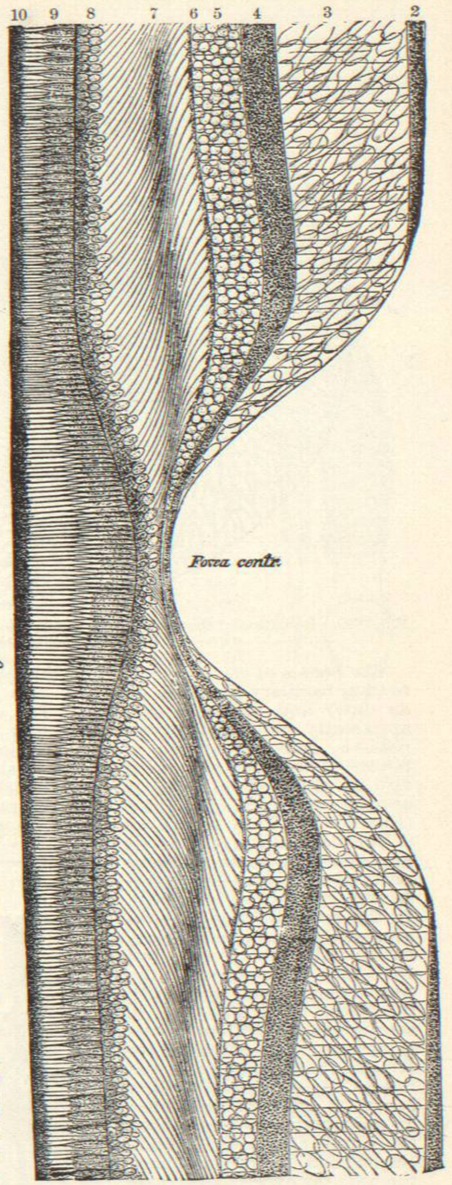

FIG. 2013.—Diagrammatic Section of the Macula Lutea and Fovea Centralis. 2, Layer of nerve fibres; 3, layer of multipolar cells; 4, internal molecular layer, composed of intertwining arborescent processes; 5, layer of bipolar cells, or internal granular layer; 6, external molecular layer, composed of intertwining arborescent processes; 7, nuclei of epithelial cells, or external granular layer; 8, frillwork formed by processes from fibres of Müller, often called the "external limiting membrane"; 9, layer of rods and cones; 10, layer of pigment epithelium.

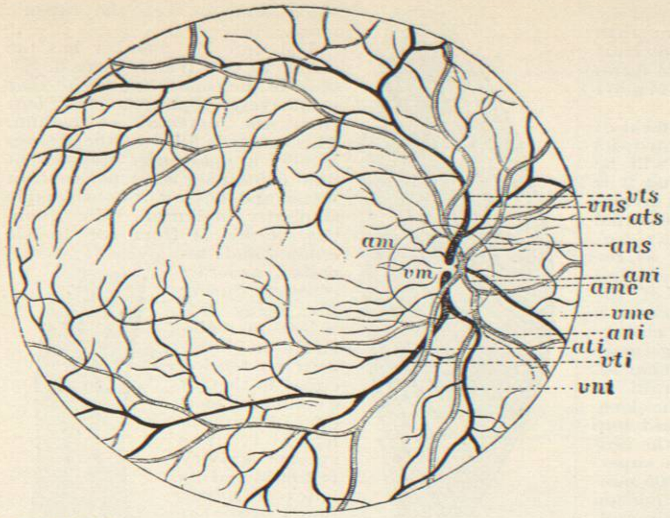

FIG. 2014.—Diagram of the Blood-vessels of the Human Retina. (Leber, after Jaeger.) *ans*, *vns*, Superior nasal artery and vein; *ats*, *vts*, superior temporal artery and vein; *ani*, *vni*, inferior nasal artery and vein; *ati*, *vti*, inferior temporal artery and vein; *am*, *vm*, macular artery and vein; *ane*, *vme*, median artery and vein.

The Ciliary Retina.—As we approach the ciliary region the highly specialized structures that characterize the fundus of the retina become changed. The cones become more scanty, the multipolar cells are fewer, the rods are shortened and disappear. Finally the elements are abruptly reduced to a simple layer of columnar epithelium. This sudden diminution leaves a line of demarcation known as the ora serrata, well seen by the unassisted eye.

The retinal blood-vessels (Fig. 2014) are derived from the central artery of the retina, which, as already stated, pierces the nerve at from 15 to 20 mm. behind the eyeball and appears on the disc at the bottom of the excavation. It immediately breaks up into two branches, the *superior* and *inferior papillary arteries*, each of which subdivides into a temporal and a nasal branch. The papular arteries also send small twigs, the *macular arteries*, toward the region of the yellow spot. Except at the optic-nerve entrance, where a capillary anastomosis occurs with twigs from the posterior ciliary arteries, all these vessels form a system independent of that of the choroid. They ramify mainly in the layer of multipolar cells and do not anastomose with each other. At the central fovea the vessels from this system are wanting (Fig. 2015), as might be expected from the absence of the inner layers at that place.

The *crystalline lens* (Figs. 2016, 2017, 2018), is a transparent biconvex body with a circular margin, applied to the opening of the pupil, touching the iris in front and resting behind in a shallow depression of the vitreous, known as the *hyaloid fossa*. Its margin is from 0.5 to 0.6 mm. from the ciliary processes to which it is united by a suspensory ligament called the *zonula*. Its diameter is from 9 to 10 mm., and, having the unique property of changing its form under the influence of the ciliary muscle for adaptation to vision of near or remote objects, its thickness varies from 3.7 to 4 mm. While not mathematically exact, its curved surfaces are nearly those of spheres, the radius of the anterior one varying from 10 to 6 mm., that of the posterior one from 6 to 5 mm., according as the lens is accommodated for distant or near objects. The fœtal lens is nearly circular; in old age it becomes flattened.

The weight of the adult lens is from 0.20 to 0.25 gm., specific gravity 1.121, volume 0.25 c.c. The central core or *nucleus* is more condensed and less elastic than the peripheral part or *cortical substance*, though its histological structure is the same. This difference does not exist in the fœtus and increases with age, depriving the lens of its elasticity, so that the eyes of elderly persons do not readily accommodate for distance. The nucleus refracts more than the cortical substance, the indices being 1.4541 and 1.4053 respectively, that of distilled water being

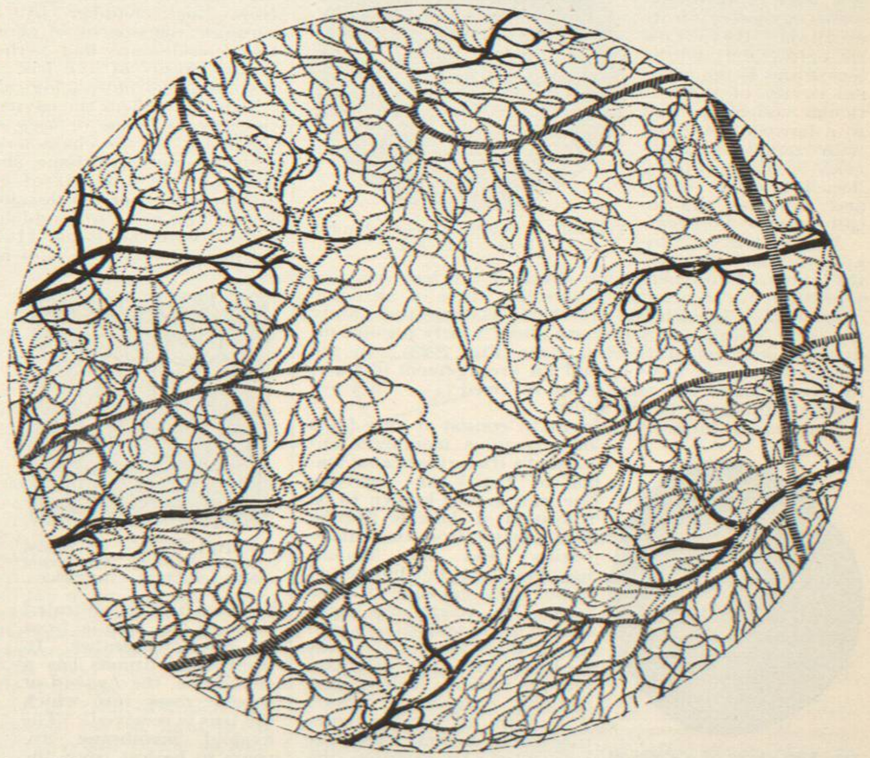
FIG. 2015.—Blood-vessels of the Macula Lutea. The part that is totally free from vessels is the fovea centralis.

1.3342 (Krause). The lens is completely enveloped by a structureless elastic capsule thicker in front than behind, which resembles in its reactions the sarcolemma of muscle or the membrana propria of glands.

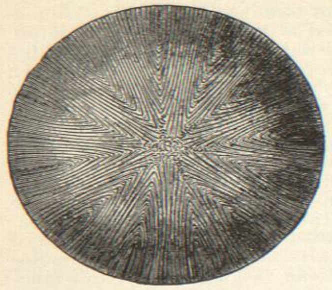

FIG. 2016.—Anterior Surface of Adult Lens. (Arnold.)

The development of the lens is the key to its structure. It will be remembered that it is formed from an invagination of the external epithelium that becomes isolated as the lenticular vesicle and that the cells of the anterior wall retain their epithelial characters, becoming more and more columnar toward the margin or equator of the lens, while those on the retinal aspect become lengthened into flattened fibres that vary in size and length in the central and the peripheral portions (Fig. 2019). The superficial fibres are from 0.010 to 0.012 mm. wide, 0.005 mm. thick, and 8 mm. long, while those of the deeper portion are 0.0075 wide, 0.0025 thick, and 4 mm. long. In the middle and interior portions of the lens the edges of the fibres are finely serrated (Figs. 2020, 2021), but these serrations do not fit into each other and there are thus left between the fibres fine spaces that serve for the passage of lymph. As the lens has no blood-vessels such a provision seems necessary for its nutrition. Between the epithelium and the lens fibres is the original cavity of the lenticular vesicle reduced to a narrow slit filled with semifluid material. This rapidly liquefies after death and becomes the so-called *liquor Morgagni*.

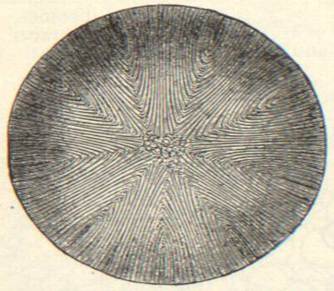

FIG. 2017.—Posterior Surface of Adult Lens. (Arnold.)

When treated by appropriate reagents the fibres of the peripheral third of the lens may be separated into concentric layers like those of an onion (Fig. 2022). In each layer the fibres have approximately the same length and terminate along nearly regular radiating lines called the *lens stars* (Fig. 2023). In the young lens these have behind an arrangement like a Y, in front that of the same letter reversed (⅄). They are more complicated in the adult.

The *zonula*, formerly thought to consist of two folds of a tenuous membrane enclosing a triangular canal (canal of Petit) that encircles the lens, is now known to be a system of delicate fibrillæ that extend from the ciliary region and the hyaloid membrane to be implanted upon the capsule of the lens. The origin and exact nature of these fibrillæ is still under discussion. It seems probable that they originate like the vitreous from mesenchymal connective tissue. They form an annular structure about 6 mm. wide that completely encircles the lens, serves to hold it in position and to keep the capsule tense.

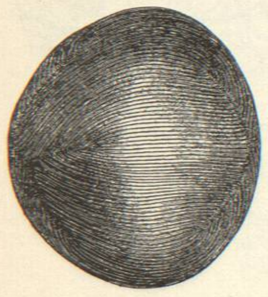

FIG. 2018.—Lens of a Child at Birth Seen from the Side. (Arnold.)

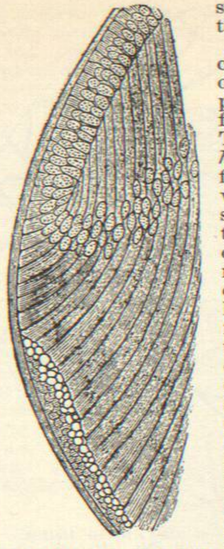

FIG. 2019.—Meridional Section Through Lens of Calf. (Arnold.)

The anterior chamber has the character of a lymph space developed in the connective tissue that primitively separates the lens from the external epithelium. This cavity is filled by the *aqueous humor*, a sparkling, transparent fluid containing 98.71 per cent. of water and having a considerable similarity to lymph. The quantity of this is from 231 to 323 c.mm. and remains nearly constant during life, being sufficient to maintain an intraocular tension equal to that of a column of mercury 26 mm. in height. Its specific gravity is 1.0053 and its index of refraction 1.3420, that of distilled water being 1.3342 (Krause). Apparently it is constantly renewed by a secretion from the vessels of the choroid, particularly those of the ciliary processes, and removed from the chamber by infiltration through the spaces of Fontana into the scleral sinus and perhaps by the lymph crypts of the iris. Normally it contains no morphological elements.

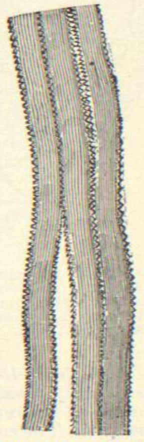

FIG. 2020.—Isolated Fibres from Lens. (Arnold.)

Behind the lens the cavity of the eyeball is filled with the *vitreous humor* or *body*, a transparent, jelly-like material that has the characters of a primitive form of very watery connective tissue, showing widely scattered cells embedded in a matrix of gelatinous material in which appropriate reagents develop a rich fibrillary network. Leucocytes are also found in it, especially where it is in contact with the retina. It has a very delicate envelope, the *hyaloid membrane*, adherent to the retina at the optic disc and the ciliary region where arteries enter during fœtal life. This membrane does not pass down into the intervals between the ciliary bodies, but spans them over, forming thus small meridional spaces, the *recesses of the posterior chamber*, which are filled with aqueous humor infiltrated through the zonula from the anterior chamber. In front the vitreous has a depression, the *hyaloid* or *patellar fossa*, into which the lens is received. The hyaloid membrane appears to be lost upon the zonula in front and not to

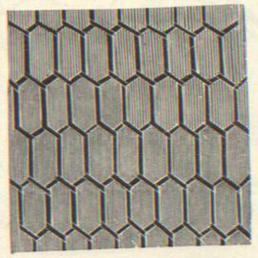

FIG. 2021.—Section of Frozen Lens Showing Hexagonal Shape of Fibres. (Arnold.)

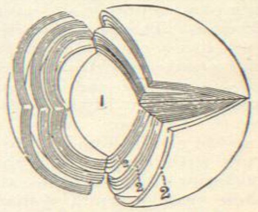

FIG. 2022.—Lamination of the Lens as Shown After Treatment with Dilute Alcohol. (Arnold.) 1, Former central portion called the nucleus lentis; 2, 2, layers of the so-called cortical substance.

be continued over the hyaloid fossa, the consistence of the vitreous at that place being maintained by a condensation of its substance. From the optic disc forward there runs in fœtal life a small vessel, the *hyaloid artery*, for the nourishment of the lens. This is represented in the adult by a central lymph space, the *hyaloid canal* (Fig. 1952). Just in front of the disc this canal enlarges to a space known as the *area Martegiani*.

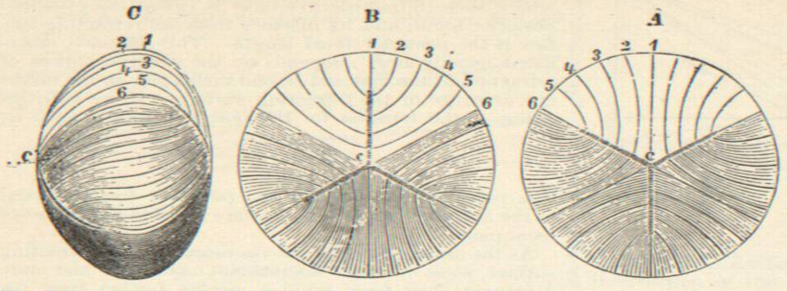

FIG. 2023.—Arrangement of the Fibres of the Lens in the Fœtus and at Birth. *A*, Posterior surface; *B*, anterior surface; *C*, side; *c*, centre of the lens stars, being the anterior and posterior poles of the lens; 1 to 6, course of fibres taken at equal distances.

The refractive index of the vitreous body is nearly that of distilled water, its weight is from 6.7 to 8.3 gm. and its specific gravity is 1.005. Its reaction is alkaline, and the proportion of water found in it is very high, being 98.40 to 98.64 per cent.

Frank Baker.

EYE, DIOPTRICS OF.—REFRACTION.—1. The term refraction refers in physics to the deviation of a ray of light from its straight path on passing from one transparent medium into another of different nature. In physiological optics, however, this term is used with a special significance, denoting the relation of the focal length of the eye to the position of the retina. The eye has a normal, or emmetropic (from ἔμμετρος, according to measure, and ὤψ, eye), refraction, if images of distant objects are sharply defined on the retina; the refraction is myopic, or near-sighted, if distant objects form images in front of the retina; while hypermetropia is that refractive state in which images of distant objects can be sharply defined only behind the actual place of the retina. Any refractive state other than emmetropia is referred to in general as ametropia (from ἄμετρος, disproportionate, and ὤψ, eye).

The eye of all vertebrates is an optic instrument, the principle of which is illustrated by the photographer's camera obscura. By means of a convex lens, the rays of light coming from the different points of external objects are so reunited as to form inverted, but geometrically correct, images of those objects on a screen. The screen is the retina, while the convex lens is constituted by all the transparent media of the eyeball.

A correct knowledge of the optic properties of the eye is not possible without some familiarity with the laws of physical dioptrics. Hence we must begin with a résumé of the laws of the refraction of light. In order to keep this article within the allotted space, we will not attempt to follow out the mathematical deduction of all the various formulæ of which we must make use. For the complete mathematical proof of all the statements the reader must consult some of the works mentioned in the bibliography, especially those of Helmholtz and Donders.

The paths of the rays of light entering the eye, and the influence of the different media upon them, can be deduced from the following optic principles:

2. *Law of Refraction.*—From every point of a luminous or illuminated object there proceed rays of light in all directions. Every ray pursues a straight course as long as it passes through a uniform medium. When a ray passes from one transparent medium into another of different optic properties, it is refracted or deflected from its straight path, except when its original direction is vertical to the surface of the second medium. The extent of deflection depends on a specific property of each medium, viz., its refractive power. The relation of the refractive power of any one medium to that of another is termed the refractive index, and is usually designated by the letter n. Air is taken as the standard of comparison, and its index of refraction is called 1. Compared with air the refractive index of water is 1.334; of crown glass, 1.533; of flint glass, 1.664. A medium having the greater refractive index is said—in a somewhat loose manner—to have a greater optic density than another rarer medium.

The extent to which a ray of light is deflected from its straight path, by refraction, depends on the angle at which it strikes the surface, as well as on the refractive indices of the media.

Let A, in Fig. 2024, be air, with the refractive index $= n$, and B be glass, with the index $= n'$, the two being separated by the surface $s\,s'$. A ray of light, having the direction $a\,c$ in the air, will be bent in the direction $c\,d$ on entering the glass. If we erect the normal $b\,c\,e$ vertical to the surface at the point c, the angle $a\,c\,b$ is the angle of incidence of the ray $a\,c$; the angle $e\,c\,d$ is the angle of refraction. The latter is here smaller than the former, for, in the denser medium, the refracted ray is bent toward the perpendicular. The relation of one angle to the other depends on the relation of the refractive indices of the two media, so that the sine of either angle is to the sine of the other inversely as the index of the corresponding medium is to that of the other, or

$$\frac{\text{sine } a\,c\,b}{\text{sine } e\,c\,d} = \frac{n'}{n} \qquad (1)$$

Since the sine of an angle zero is likewise zero in value, it follows that when the incident ray is itself perpendicular to the refracting surface, it continues to be perpendicular after its entrance into the second medium, *i.e.*, it is not deflected at all from its course.

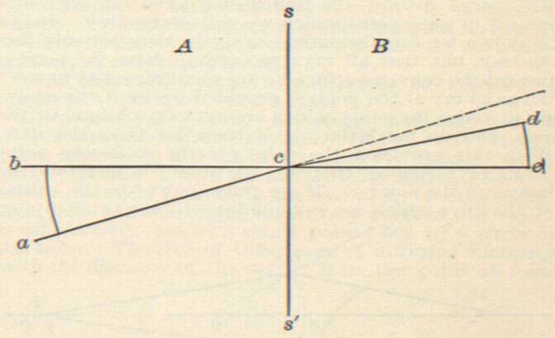

FIG. 2024.

The path which a ray describes in passing through one or more refracting surfaces is the same, whether that ray travels forward or backward from any given point in its course.

3. If the denser medium is in the form of a plate bounded by parallel surfaces and surrounded by the same rarer medium on both sides, a ray, after passing through the plate, follows a direction parallel to its original course, but is displaced laterally.