section showed a sarcomatous-like structure of round and spindle cells grouped around blood-vessels, suggesting an endothelioma. Study of the sections showed large numbers of plasma cells present, and the fact that all of the blood-vessels had relatively thick walls. A diagnosis of omental granulation tissue was then given. A year afterward the tumor was reported as having entirely disappeared. There can be but little doubt that some of the so-called disappearing malignant tumors of the abdomen belong to this class. The microscopical appearances of small bits of tissue removed for diagnosis may on first glance strongly suggest a sarcomatous growth. In the relatively thick sections obtained by means of the freezing microtome or by quick embedding methods the finer points necessary to a differential diagnosis are usually not sufficiently clear for a safe diagnosis, and it is from such sections that the diagnosis of sarcoma is usually made. The writer holds that in carefully prepared sections the differential diagnosis between such forms of richly cellular granulation tissue and sarcoma may be made without great difficulty. The presence of numerous plasma cells, the prominence of the small vessels, both in number and in size, their relatively thick walls, the hypertrophic character of their endothelium, the marked endothelial proliferation, the typical character of the mitosis, the presence of fibrin and small pus collections, are all points establishing the diagnosis of subacute or chronic development of granulation tissue. The presence of adipose tissue and coarse trabeculæ of fibrous tissue are also of service in fixing the origin as omental.

Omental Abscess.—An acute omental abscess may develop without the association of a general peritonitis or of any discoverable local change. In the majority of cases, however, the appendix is the seat of primary infection. Omental abscess may be associated with salpingitis, and very frequently follows laparotomies or herniotomy. In those cases in which the omental abscess is apparently of cryptogenic origin, or overshadows the primary lesion, it may be inferred that the resistance of the omental tissues had been lowered, or that the organ, through circulatory disturbances or for other reasons, has been unable to overcome the virulence of the bacteria taken up. The abscess may be found in any part of the abdominal cavity, but as the omentum is commonly rolled up, it lies usually above the level of the umbilicus. It may develop around ligatures which are used in tying off the omentum. The organ is reddened, thickened, and is usually adherent to the abdominal wall by a fibrinous exudate, which is most marked over the abscess. The latter not infrequently forms an encapsulated pocket of pus between the omentum and the anterior abdominal wall, and may extend into the tissues of the latter. The clinical symptoms are those of sepsis, with local pain and tumor. In many cases the abscess becomes chronic, a large amount of fibrous tissue is formed about the encapsulated area, the adhesions become hard and firm, and a gradual healing of the abscess may take place. A more or less generalized peritonitis may accompany the abscess. Occasionally the pus may break through into the intestine and recovery follow. Rupture into the peritoneal cavity may cause a severe general peritonitis which may be fatal.

Sequelæ of Omental Inflammation.—As a result of inflammatory conditions of the omentum there may arise adhesions between the organ and the various abdominal viscera; these may cause stenosis, or snaring off of portions of the bowel, obstruction of the ureter, pressure upon the common duct or pylorus, abnormal position of the pelvic organs, etc.

PROGRESSIVE CHANGES.—Either fibrous or fatty *hyperplasia* of the omentum may occur in the portion of the organ included in hernial sacs. The hyperplasia may take on the character of a lipomatous growth. Cases have been reported of such hyperplasias in hernial sacs which reached half-way to the knees.

The remarkable capacity for *proliferation* possessed by the omentum has been taken advantage of in plastic operations in the abdomen. (For further details in regard to this part of the subject, the reader should consult the article next beyond this.)

Tumors.—Primary neoplasms of the omentum are rare. *Fibroma* and *lipoma* have been described. In the former class of cases the actual disease may in reality have been a localized fibroid thickening resulting from an inflammatory omental tumor. The so-called lipomatous growths have been, in the majority of cases, localized or diffuse fatty hyperplasias.

Of the primary malignant tumors reported as occurring in the omentum *endothelioma* and *myxosarcoma* are the forms whose origin in this organ is supported by observation; but it must be observed that the rarity of such cases, and the imperfect descriptions given, leave us very much in ignorance as to the occurrence and nature of primary omental tumors. In the older literature there are occasional reports of "*primary cancer*" of the omentum, "scirrhus of the omentum," and "primary colloid disease," "vesicular degeneration," "hydatid disease," etc. The exact nature of this peculiar growth of the omentum, apparently primary in some cases, cannot at present be stated. Primary epithelial growths (carcinoma) of the omentum of course do not occur. In some cases the growth may have been secondary to colloid carcinoma of the stomach or intestine, or to cystocarcinoma of the testis or ovary. In typical cases the omentum is greatly thickened; its surface is uneven, flocculent, and shreddy, this appearance being due to the projection of rounded villus-like masses of gelatinous material attached by shreds of tissue. The appearance strongly suggests hydatid disease of the placenta. On microscopical examination the mass of the omentum has a finely spongy texture of connective tissue enclosing masses of gelatinous material. Swollen cells are occasionally found in the spaces. If we exclude the cases of true *colloid cancer* or *cystocarcinoma, secondary* to primary tumors in other organs, there still appears to be a peculiar myxomatous growth of the omentum, which according to the most careful reports (Eve and others) must be classed as a *myxoma* or *myxosarcoma*. No proof of its endothelial origin exists. Matas has reported a case of primary myxosarcoma of the omentum with secondaries in peritoneum and accompanied by a mucoid ascites.

The flat or warty growths, originating from endothelium, may be primary in the omentum as well as in the peritoneum. Microscopically, the primary endotheliomata of the peritoneum consist of cords or strands of cells in the connective tissue beneath the endothelial covering. The cords of cells appear to follow the lymph vessels. The growth may originate from the superficial layer, or from the endothelium of the lymph vessels.

Omental *cysts* have also been reported, and have been interpreted as "*simple serous cysts*," "*distended lymph vessels*," "*congenital multilocular cystoma*," etc. It is not improbable that the latter variety was a primary tumor of the ovary, which after becoming adherent to the omentum, had been freed from its original attachments. Such a process has undoubtedly occurred in the case of the so reported *dermoid cysts of the omentum*. Though primary dermoids of the omentum may occur, it is highly probable that those observed have originated from primary ovarian dermoids in the manner described.

Secondary malignant growths of the omentum are of very common occurrence; they represent most frequently carcinoma metastases from primary growths in stomach, intestine, gall-bladder, pancreas, ovaries, testis, uterus, and prostate. A number of cases of melanotic sarcoma of the omentum have been reported. While the growth, in several of these instances, was regarded as primary, it undoubtedly was metastatic from primaries in the skin or choroid.

Pseudomyxoma.—The omentum as well as the general peritoneal surface may be involved in the process known by this name. It is due to rupture of an ovarian cystoma, the discharge of mucoid or colloid material into the peritoneal cavity, and the organization of the latter by proliferation of the peritoneal tissues.

PARASITES.—*Echinococcus* of the omentum has been reported. After rupture of a primary hydatid cyst into the peritoneal cavity the omentum may be secondarily involved in connection with the remainder of the peritoneum.

Tuberculosis of the omentum is of relatively common occurrence. In many cases the infection of the peritoneum appears to be primary in the omentum. The thickened omentum may be tightly rolled up, forming a tumor-like mass which may be mistaken for a neoplasm. In primary tuberculosis of the female genital tract, large tubercles may be found in the omentum. (See also *Peritonitis, Septic and Tuberculous.*)

Syphilis.—A fibroid omentitis has been observed in congenital syphilis, and in connection with syphilitic cirrhosis and fibroid splenitis.

Foreign Body.—A case is reported of an encysted needle being found in the omentum. Gauze, sponges, ligatures, or foreign bodies left in the peritoneal cavity during laparotomy may become included in omental adhesions.

Aldred Scott Warthin.

OMENTUM, SURGERY OF.—The omentum is composed of two layers of peritoneum which are derived from the anterior and posterior walls of the stomach. They pass downward in front of the abdominal organs into the hypogastric region, and are reflected backward upon themselves and pass upward until they reach the transverse colon. There they separate, and after covering this portion of the intestine they come into contact behind it, forming the transverse mesocolon. Thus the omentum is really made up of four layers, but in adult life the layers cannot be wholly separated, although this construction gives to the omentum a very loose and lobular character. In almost all persons the omentum contains a good deal of fat, and in individuals who are very stout the quantity of fat is proportionally large.

The function of the omentum under normal conditions seems to be to afford protection to the underlying coils of small intestine, and also to facilitate their movements. Under pathological conditions it has the further function of applying itself to any wounded surface of the peritoneum within reach, so that it may even be able to occlude a perforation and prevent fatal escape of intestinal contents. By reason of its large serous surface it doubtless aids materially in the resorption of extravasated fluids from the peritoneal cavity.

The lesions of the omentum which are of surgical importance are traumatic, inflammatory, parasitic, and neoplastic.

Traumatisms.—If the abdominal cavity is opened, for example, by a stab, the omentum will often be found presenting itself in the wound. It frequently serves a useful purpose by protecting other more important organs from exposure to infection and traumatism in an open wound. It may even protrude through a stab wound which opens both the lower part of the pleural cavity and the peritoneal cavity through the diaphragm. It is the most common content of a hernial sac. The omentum which is thus prolapsed into a wound may be uninjured, or some of its vessels may have been opened by the traumatism, or it may become inflamed, or it may become gangrenous either on account of the traumatism or secondarily through its becoming strangulated in the wound.

Intraperitoneal hemorrhage from a larger omental vessel may prove fatal because the thin walls of its vessels favor long-continued bleeding. In excising prolapsed or injured or adherent portions of omentum the surgeon should be careful to see that every bleeding vessel is secured by a ligature. If the omentum which presents itself in a wound is uninjured and the wound itself is clean, the omentum may be cleansed and replaced; otherwise it should be cut away.

Inflammation.—The simplest form of inflammation which can affect the omentum is of a traumatic character. This is most frequently seen in connection with an omental hernia, where repeated slight traumatisms give rise to local fibrinous peritonitis with the formation of adhesions. The hernia will then become partly or wholly irreducible and the omentum will be still more exposed to slight injuries. This condition is often seen in inguinal and umbilical herniæ. In operating upon such herniæ, it is customary to excise portions of omentum which are badly matted together by adhesions, or whose surfaces are deprived of their peritoneum when the omentum is torn loose from the hernial ring. The removal of more or less of the omentum does the patient no harm, but the stump of the omentum may give rise to serious trouble. It sometimes retracts, and becomes adherent to the abdominal wall or some portion of the intestine, while adhesions take place about it to such an extent that a mass is formed that has more than once been mistaken for a tumor. In one case within the knowledge of the writer a section of this new-formed fibrous tissue was removed and was pronounced by a well-known pathologist to be a spindle-celled sarcoma. In consequence an extensive resection of the descending colon, to which the omentum was adherent, was performed, and from the indirect effects of this operation the patient died. Such an inflammatory tumor in the omental stump will, like all ciatricial tissue, decrease in size in the course of time, but it may give the patient a great deal of trouble during the process, and the adhesions produced by it may continue to give trouble long after the inflammation has subsided.

Suppurative inflammation may develop in the omental stump, usually as the result of an infected ligature. If general peritonitis is avoided, an abscess may be produced within the omentum. The omentum under such circumstances will attach itself to the surrounding parts, including the anterior abdominal wall, so that it may be possible to open the abscess without entering the general peritoneal cavity.

The more chronic inflammations, such as syphilis, tuberculosis, and actinomycosis, may involve the omentum, usually in common with other portions of the abdominal cavity. Omental echinococcus is also known, and in very rare instances an echinococcus cyst of the omentum reaches a great size, although the lesions in other portions of the peritoneum are insignificant.

Tumors.—A few primary tumors of the omentum have been reported. They are for the most part lipomata, sarcomata, or cystic tumors of congenital origin. Dermoid cysts and teratomata are thus explained. There are also acquired cysts of the omentum of a serous or hemorrhagic character, the latter being secondary to hæmatoma. Thus the tumors of the omentum are similar to those of the mesentery.

In addition to these primary tumors of the omentum secondary nodules may develop on its surface and within it in case of malignant disease of other abdominal organs, while tumors of the transverse colon may grow downward into the omentum so that they simulate omental tumors. A careful examination after the abdomen is opened will usually show the starting-point of such a tumor.

An omental tumor is characterized by a great range of mobility as long as adhesions do not exist. For this reason a small cyst may easily be mistaken for a solid tumor. As tumors of the mesentery often have a great mobility, it will scarcely be possible to differentiate them from omental tumors before the abdomen is opened.

The removal of an omental tumor requires no special technique. On account of the thin walls of the vessels all bleeding should be stopped by ligature before the abdomen is closed. Mass ligatures cannot well be avoided, but the amount of tissue included in each ligature should be small. It is also worth while to approximate the peritoneal surfaces of the omentum by a continuous catgut suture so as to prevent the formation of extensive adhesions. If an echinococcus or epithelial cyst cannot be removed *in toto*, it should be sutured into the abdominal wound and drained.

Omental Grafts.—The omentum has occasionally been used to cover a defect in the peritoneum which could not be closed by direct suture or as an additional safeguard

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to cover a weak suture of the stomach or intestine. It is especially adapted for such a purpose because of its extensive peritoneal surface, its great mobility, and its free blood supply. Furthermore, the omentum can be sacrificed without especial injury. The advantage of covering all wounded surfaces within the abdominal cavity with peritoneum has not been generally recognized, yet when this is done repair is hastened and the risk of sepsis is lessened as truly as is the case in covering wounded surfaces of the body with skin, while within the abdominal cavity a raw surface has a third disadvantage not possessed by external raw surfaces in that it gives rise to adhesions more or less dangerous, according to their situation. Such adhesions can be partly or wholly avoided if the raw surface is covered with peritoneum. The omentum has been used with success to supply peritoneal grafts, which may remain attached to the omentum, or may be wholly cut from it and stitched over the wounded surface like a skin graft over a raw external wound. The wound in the omentum itself should of course be closed by suturing the cut edges of the peritoneum. *Edward Milton Foote.*

ONYCHIA. See *Hands and Fingers, etc.*

OPEN-AIR TREATMENT OF PULMONARY TUBERCULOSIS.—The so-called "open-air" treatment of pulmonary tuberculosis has been adverted to frequently in this HANDBOOK, notably under *Falkenstein*, *Goerbersdorf*, and *Health Resorts.* It is the established treatment of pulmonary tuberculosis at the present day, and is most completely exhibited in the sanatoria. In a word, it consists in affording the patient pure outdoor air to breathe continuously, both night and day, keeping him out of doors by day and having his bedroom windows open by night, or in many cases and places having him sleep also out of doors. It is hardly necessary to add that at the same time due attention should be paid to diet, rest, hydrotherapy, and to all that pertains to the hygienic well-being of the patient; hence this method is also, and perhaps more correctly, termed the "hygienic-dietetic" treatment. This treatment has been brought to such a degree of perfection that it may almost be said to be independent of climate, that is, it can be successfully carried out wherever there are pure air free from dust, protection from wind, and a moderate amount of sunshine—climatic conditions which are obtainable almost everywhere outside of large centres of population. It seems a very simple matter to conduct such a treatment, but experience has shown that constant supervision is necessary, aided by the example of others, in order to keep the patient up, day after day, summer and winter, to this treatment in all its strenuousness; hence the great value of sanatoria and their constant and rapid increase in number. Even though this treatment is in a measure independent of climate, it is not to be asserted that all climates are equally valuable, for it is obvious that the greater the number of favoring climatic elements, the more perfectly the treatment can be conducted, and the more successful it will be. Hence such resorts as Davos, Colorado Springs, Idylwild (California), Asheville, Aiken, and many others of superior climatic excellence are especially favorable for this mode of treatment, provided the other essential factors, such as diet, etc., are at hand. It may be thought that this treatment can be accomplished by simply instructing the patient to keep out of doors; nothing could be more fallacious than this. In the first place, the patient will not keep out of doors all day of his own volition. If he is out for a few hours each day, he is prone to think that he is fulfilling his instructions. Further, he is too often left to himself to determine whether he shall remain at rest or take exercise while in the open; generally he does the latter, sometimes from ignorance, sometimes for the want of any proper place where he can remain at rest. Here, again, comes in the value of the sanatorium where all these details are carefully looked after.

The theory of the outdoor treatment is, of course, evident; the object is so to improve the nutrition of the pulmonary tissue and general system, and so to harden the patient and thereby increase his resisting power that he will no longer present a favorable soil for the tubercle bacillus. It is also claimed for this treatment that it will increase tissue metabolism, so that fibroid transformation of tuberculous lung tissue may be hastened, or the encapsulation of caseous areas effected.

Are all cases of pulmonary tuberculosis suitable for the open-air treatment? Obviously not, for all cases are not susceptible of an arrest or improvement; and the object of this treatment is to *cure.* Although it is difficult, if not impossible, in many cases and in the various stages of the disease, to form a probable prognosis, still in general it may be said that advanced cases with mixed infection and septic symptoms—cases of very extensive disease, those in which the tuberculous process is accompanied by acute symptoms, or those in which the recuperative power seems to be lacking, and the whole system appears to have collapsed—are unfavorable cases and unfitted for the severe régime of the open-air treatment. Fresh air, of course, should be afforded all cases, as to everybody else, sick or well; but this can be done in a well-ventilated room, where the patient is made comfortable and kept at rest. If some of these apparently hopeless cases later exhibit more favorable symptoms and develop greater recuperative power, they then can more properly be subjected to the open-air treatment.

Lest there may be some misunderstanding, it is well again to state what may seem self-evident, viz., that the open-air treatment in all its rigorousness means practically a continuous outdoor existence. Day after day in all kinds of weather one must be exposed to the open air, and the windows of his sleeping-room must be kept open day and night, summer and winter. This does not mean that one shall sit out in a rain or snow storm, but on a veranda for example, which affords shelter from the storm and wind and yet is open to the air. The writer, for example, had a patient at Rutland, Mass., who, during a New England winter, spent eight hours daily out of doors, always slept in a cool room, with open windows, and bathed his chest every morning with cold water.

In Colorado Springs it is quite generally the custom for consumptives to sleep out of doors, even in winter, with face and body well protected. This is more readily done in warmer climates, as in Phœnix, Arizona, for example, where the practice is quite general. It is also a practice, with some, to sleep with the head out of doors, well protected, while the body is within. As a rule, the vitality and bodily vigor of a consumptive are low, and hence the greater part of the time out of doors is spent at rest, best on a reclining or ship's chair. One of the common sights at the German sanatoria is the "Liegehalle" or piazza, where are long rows of patients in reclining chairs. Dettweiler insists upon almost complete rest in the open air, while other phthisio-therapeutists permit their patients who have no fever to take a limited amount of exercise. As has been said above, a well-equipped sanatorium affords the best opportunity for taking the open-air treatment, and medical supervision is always at hand to insist upon it; at the same time it is practicable, in very many cases, to devise at the home of the patient an arrangement for this treatment. A properly protected veranda, preferably facing the south; a tent with a wooden floor; a country barn with the large doors open; a shed or wooden chalet simply and cheaply constructed, serving also as a sleeping-room by night;—all of these afford opportunities for the "treatment." If the physician is at all ingenious he will readily invent some way by which this can be accomplished, for there is almost always something in or about the patient's house that can be utilized for this purpose.

It is hardly necessary to say that a patient used to an indoor life, as the great majority of them are, must be somewhat gradually accustomed to a constant open-air exposure, but it is marvellous how perfectly they establish the habit, and how complete is the endurance which they attain. Knopf ("Prophylaxis and Treatment of

Pulmonary Tuberculosis") quotes Andvoid, of Tonsaasen, Norway, as saying that he leaves his patients on their chairs, wrapped in furs, for from five to nine hours a day at a temperature of 25° C. (− 13° F.).

The number of hours during which the patient remains out of doors depends largely upon the location and latitude of the resort. At Davos, for example, the sun rises late and sets early, on account of the surrounding mountains, so that a winter's day is only about four or five hours long. In Falkenstein the patients remain out of doors for from seven to ten hours a day all the year through; at Rutland, Mass., for about eight hours; at Colorado Springs for from seven to eight.

The effects upon the patient of this prolonged stay in the open air are striking. Appetite and weight increase; cough and expectoration diminish; and if there is any rise of temperature at any part of the day, this is likely soon to disappear. The patient also experiences a sense of well-being and invigoration, together with mental exhilaration. After a course of open-air treatment one is no longer content to live indoors or sleep with closed windows.

It may be pertinently asked if patients do not catch cold under this constant open-air exposure. On the contrary, experience has proved that they are less likely to do so than when they live under constant protection with the consequent unavoidable exposure to impure air. The constant exposure to pure germless air, however cold, when one is properly clad, does not render one susceptible to catching cold, as Nansen so strikingly proved on his Arctic expedition.

In conclusion, it is well to reiterate that the open-air treatment is not the whole treatment of pulmonary tuberculosis. In addition, there must be an abundance of nutritious and properly prepared food; rest; a most careful avoidance of over-exertion either mental or physical; moderate exercise under careful supervision, and in suitable cases; and due attention to the skin by the use of various hydrotherapeutic measures. In brief, all the hygienic measures conducive to the invigoration of the general system, must be adopted. *Edward O. Otis.*

OPHTHALMIA, PURULENT. See *Conjunctiva, Affections of.*

OPHTHALMOMETER.*—An instrument for measuring the curvature of the refracting surfaces of the eye.

Thomas Young (1801)[1] was the first investigator to attempt accurate measurements of the curvature of the cornea in the living eye. By measuring the diameter and the prominence of the cornea, he found the chord and versed-sine of an arc of a corneal meridian; from these data he calculated the radius of curvature. Young's estimate of the curvature of the cornea agrees very closely with the results which have since been obtained by more refined methods.

Kohlrausch (1840)[2] measured the image of a distant object viewed by reflection at the anterior surface of the cornea, as in a convex mirror, and thus laid the foundation of ophthalmometry in the modern sense. The object used by Kohlrausch was a pair of candle flames placed behind small openings in an opaque screen. The images of the two bright points were viewed through a small astronomical telescope, constructed for observing at a distance of from two to three feet, and their positions marked by two adjustable spider lines in the eyepiece. The length of the image (distance separating the images of the two points of light) was then read, through the telescope, on a finely divided scale placed as nearly as possible at the distance at which the image had been observed.

Now the object and the image lie at conjugate foci of the cornea, considered as a convex mirror, and the relations of the two focal distances is expressed by the equation

* The writer desires particularly to acknowledge his indebtedness to Dr. John Green, of St. Louis, for assistance most kindly rendered in revising the present article for the press.

$$\frac{1}{f'} - \frac{1}{f} = \frac{2}{r};$$

or

$$r = 2f \cdot \frac{f'}{f - f'}; \qquad (1)$$

in which

r = the radius of curvature of the cornea;

f = the distance of the object from the surface of the cornea;

f' = the distance of the image from the surface of the cornea.

As the observing distance is taken at between two and three feet, and the object is stationed at as great or at a greater distance, f is quite large in comparison with f'; it is admissible, therefore, without sensibly affecting the accuracy of the equation, to disregard f' in the denominator of (1) and to write the equation in the simplified form:

$$r = 2f \cdot \frac{f'}{f} = 2f'.^{*} \qquad (2)$$

Again, the length of the object is to the length of the image in the ratio of their respective distances from the centre of curvature of the convex mirror (cornea).

Designating these distances by g and g' respectively, we have

$$\frac{g'}{g} = \frac{\text{length of image}}{\text{length of object}}.$$

But

$$g' = r - f'$$

and

$$g = r + f'$$

whence

$$\frac{r - f'}{r + f} = \frac{\text{length of image}}{\text{length of object}};$$

or

$$r - f' = (r + f) \cdot \frac{\text{length of image}}{\text{length of object}}. \qquad (3)$$

In the right-hand member of (3) neglecting r, which is small compared with f, and in the left-hand member of (3) substituting for f' its value $\frac{1}{2}r$ derived from (2), we have, as a sufficiently close approximation, the simplified equation

$$r = 2f \cdot \frac{\text{length of image}}{\text{length of object}}.^{\dagger} \qquad (4)$$

* To test the error involved in the use of this simplified equation, compare the values of r derived from (1) and (2) in a special case. For example:

Let $f = 0.8$ metre $= 800$ millimetres,
Let $f' = 4$ millimetres,

then by (1)

$$r = 1600 \cdot \frac{f'}{796} = 2.01 f';$$

and by (2)

$$r = 1600 \cdot \frac{f'}{800} = 2.00 f'.$$

The value of r by (2) is therefore too small by $0.01\ f' = 0.01 \times 4$ millimetres $= 0.04$ millimetre, which is within the limit of error in observation.

† To test the error involved in the use of (4) compare the values of r derived from (3) and (4), in a special case. For example, as in the previous note:

Let $f = 0.8$ metre $= 800$ millimetres,
Let $f' = 4$ millimetres.

Then by (3) [using for r in the right-hand member and for f' in the left-hand member their values as given by (1),]

$$r - \frac{r}{2.01} = (800 + 8.04) \cdot \frac{\text{length of image}}{\text{length of object}} \text{ millimetres,}$$

whence

$$r = 1608.08 \cdot \frac{\text{length of image}}{\text{length of object}} \text{ millimetres,}$$

and by (4)

$$r = 1600 \cdot \frac{\text{length of image}}{\text{length of object}} \text{ millimetres}$$

The value of r by (4) is therefore too small by

$$\frac{8.08}{1600} = 0.005 = \text{about } \tfrac{1}{2} \text{ per cent}$$

It should be further remarked that the use of the equation

$$\frac{1}{f'} - \frac{1}{f} = \frac{2}{r}$$

is permissible only on the assumption that the diameter of the convex surface at which rays are reflected to form the virtual image is small

The results obtained by Kohlrausch, also by Senff (1846), [3] who carried the investigation somewhat further, correspond very closely with measurements which are now generally accepted. The later development of ophthalmometry has been in the direction of perfecting the instrument for purposes of scientific investigation, and of adapting it to clinical use.

The ophthalmometer was perfected, as an instrument of scientific research, by Helmholtz (1854).[4] With the addition of a large graduated circle, arranged to carry lamps, it was employed by Donders and Middleburg to measure the curvature of the cornea in different meridians.

The ophthalmometer of Helmholtz is essentially an adaptation of the heliometer of Clausen (1841).[5] A divided plate of thick glass with parallel surfaces is mounted in a cubical box fixed in front of the objective of a small astronomical telescope constructed for observing at a distance of from 0.5 metre to 1 meter, so that each half of the glass plate covers half of the objective. The two halves of the divided plate are arranged to turn in opposite directions on a common axis at right angles to the axis of the telescope, and the amount of rotation is read to tenths of a degree on a graduated disc fitted with a vernier. So long as the two halves of the glass plate are in the same plane, perpendicular to the axis of the instrument, an object seen through the telescope appears without displacement and single; but any rotation of either half of the plate gives rise to a displacement of the image formed by the corresponding half of the objective, and this displacement increases with the rotation. As the two halves of the plate are rotated simultaneously in opposite directions the displacement of the images is also in opposite directions, and the total displacement is double what it would be if either half of the plate were rotated separately through the same angle.

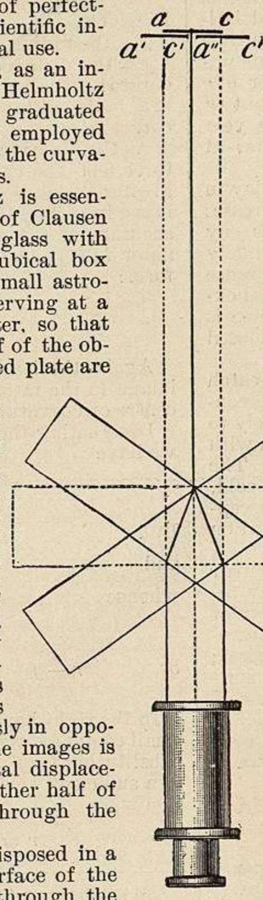

FIG. 3633.

The object (three points of light disposed in a row) as seen by reflection at the surface of the cornea is focussed by the telescope through the glass plates in the zero position—*i.e.*, with both plates set at right angles to the line of vision. The graduated disc is then turned until the two images are seen touching each other, but not overlapping, in which position of the plates the displacement of each image is exactly equal to half the length of the image. The amount of displacement (x) of either image depends on the index of the refraction (n) of the glass of

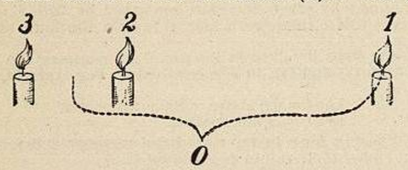

FIG. 3634.

which the plate is made, the thickness (h) of the glass plate, and the angle (ϕ) through which the plate has been rotated as expressed in the equation

$$x = h\,,\ \frac{sin\ (\phi - \phi')}{cos\ \phi},$$

the value of ϕ' being dependent on that of ϕ, as expressed in the equation

$$sin\ \phi = n.\ sin\ \phi';$$

in comparison with the radius of the sphere. This implies that the image must be small in comparison with the radius of curvature of the cornea, or, what amounts to the same thing, that the object must be small in comparison with its distance from the observed eye.

as the displacement of each image is equal to half the length of the image, we have

$$\text{length of image} = 2\,x = 2\,h\,,\ \frac{sin\ (\phi - \phi')}{cos\ \phi'}. \qquad (5)$$

In practice all calculation is dispensed with by making use of a table of successive values of $2\,x$ corresponding to different readings of the ophthalmometer, as ascertained by experiment.

As the distance of the object is quite large in comparison with the radius of curvature of the cornea, it is admissible to calculate the latter by the use of the simplified equation

$$(4) \qquad r = 2f,\ \frac{\text{length of image}}{\text{length of object}}.$$

Fig. 3633 shows the arrangement and the working of the glass plates, $a'\ c'$ and $a''\ c''$, representing the image a, c, as doubled by the rotation of the two plates in opposite directions.

Fig. 3634 shows the arrangement of the three lights, whose double images are viewed by reflection at the surface of the cornea; the image of 1 is brought by the rotation of the plates into a position midway between 2 and 3, as shown in Fig. 3634.

It will be seen from (5), also from inspection of Fig. 3633, that the size of the image is determined by the amount of rotation of the plates as indicated by the reading of the graduated disc, and is independent of the observing distance; also that, from the principle of construction of the ophthalmometer, the measurements may be made with great accuracy and without being materially impeded by slight movements of the observed eye.

Helmholtz also made direct measurements, with his ophthalmometer, of the real image of a pair of lights as seen by reflection at the posterior surface of the crystalline lens, and by an ingeniously devised indirect method he measured with the same instrument the much fainter virtual image formed by reflection at the anterior surface of the lens. By repeated measurements made upon the same eye in a state of accommodative relaxation and in accommodation for the near, he obtained the necessary data for calculating the radii of curvature of both surfaces of the lens in each of these two conditions. The measurements of Helmholtz were repeated with some modifications of the technique by H. Knapp (1860).[6] Knapp also measured the curvature of the cornea, mostly in the horizontal and vertical meridians, in a series of cases of astigmatism (1862).[7]

To adapt the ophthalmometer to the measurement of the curvature of the cornea in any required meridian,

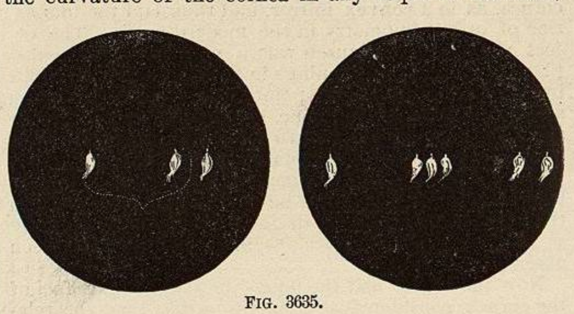
FIG. 3635.

Donders and Middelburg (1863)[8] added a graduated circle, bearing lamps (see Fig. 3637). They measured the curvature of the cornea in a large number of eyes in twelve meridians, thereby adding greatly to what had

been previously known regarding the different forms of astigmatism.

Coccius (1867)[9] substituted a fixed plate cut from a doubly refracting crystal of Iceland spar for the movable glass plates used by Helmholtz. The amount of displacement of the image formed by the extraordinarily refracted rays is determined by the thickness of the plate, and is constant; the size of the object (distance separating the lights) is therefore varied, until the two images are seen to touch each other without overlapping. The radius of curvature of the cornea is found from the simplified equation:

$$(4) \qquad r = 2f,\ \frac{\text{length of image}}{\text{length of object}}.$$

The ophthalmometer of Javal-Schiötz (1881)[10] is especially designed for the clinical investigation of the curvature of the cornea in all meridians, and is admirably adapted to its purpose. Two strongly illuminated targets (*mires*) of white enamel replace the lights, and the doubling of the image is effected by means of a doubly refracting prism of Iceland spar, which is achromatized, and at the same time a little more than neutralized for the ordinary rays by the addition of a prism of flint glass turned in the opposite direction. With this construction of the prism, the two images of the pair of targets, formed, the one by the ordinary and the other by the extraordinary rays, are displaced equally in opposite directions; the aggregate displacement of the images for the distance at which the eye

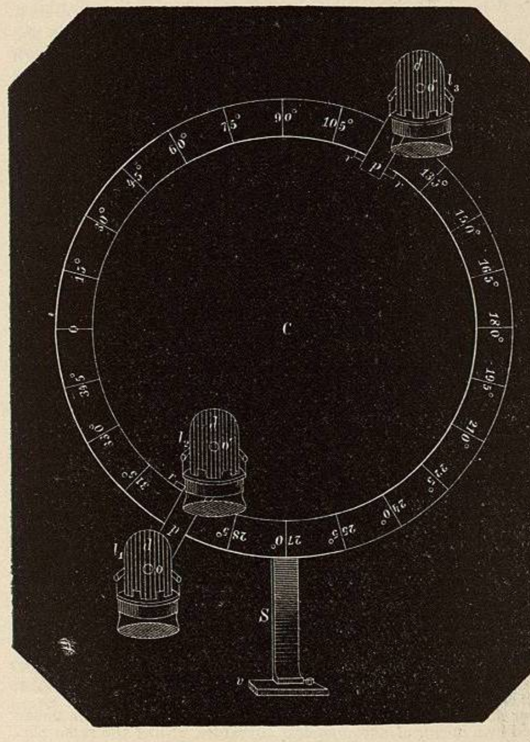
FIG. 3636.

is observed is 3 mm. The two targets ($M\ M$, Fig. 3637), are arranged to slide on a graduated arc of 0.35 metre radius, turning with the tube of the telescope. The head of the patient is supported by the head-rest, so that the centre of curvature of the cornea shall lie approximately at the centre of curvature of the arc. A more exact adjustment of the distance is then secured by moving the telescope, with its stand, until the doubled images of the two targets are seen sharply defined by reflection at the surface of the cornea; the telescope is constructed for dis-

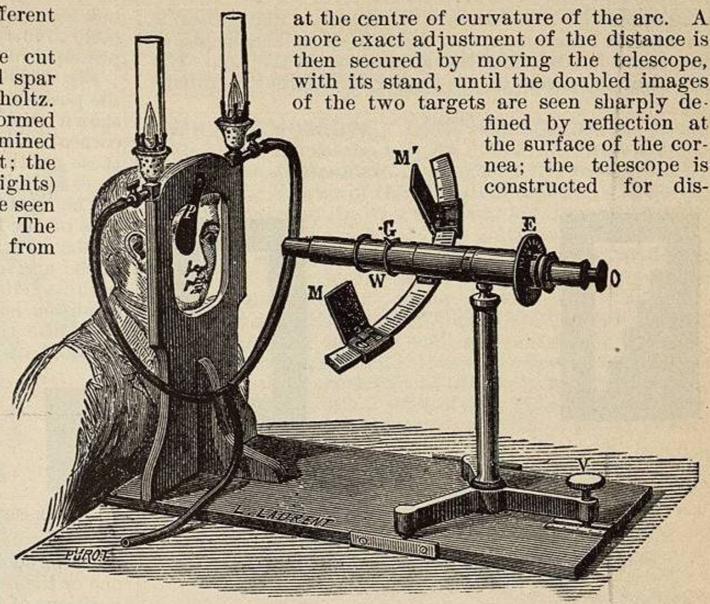

FIG. 3637.—Ophthalmometer of Javal-Schiötz, Original Model.

tinct vision at the distance of the image, which is formed about 4 mm. behind the centre of the cornea. The doubly refracting prism is in the part of the tube marked $G\ W$, and the meridian in which the arc and targets stand is read on the graduated disc at E. The eye under examination is directed upon the end of the telescope; the other eye is covered by the pivoted screen P.

As the effect of the doubly refracting prism (at the con stant distance, $f = 0.35$ metre, of the targets from the eye) is to separate the two images exactly 3 mm., it is evident that when the length of the object (chord $M\ M'$, separating the outer sides of the two targets) is so adjusted as to allow the two images to touch each other without overlapping, the length of the image must be just 3 mm. We have then, approximately,

$$(4) \qquad r = 2f,\ \frac{\text{image}}{\text{object}} = 700,\ \frac{3}{\text{chord } M\ M'} \text{ millimetres.} = \frac{2100}{\text{chord } M\ M'} \text{ millimetres.*}$$

It will be observed that in this solution, $2f\ (= 2 \times 0.35$ metre $= 700$ mm. and *image* ($= 3$ mm.) are constants,

* It will be remarked that, by the construction of the Javal-Schiötz ophthalmometer, the distance of the targets from the observed eye is rather small, and the image is rather large in comparison with the radius of curvature of the cornea (see page 363, footnote). In the use of equation (4) there is, therefore, a considerable margin of error, though not enough to detract from the usefulness of the instrument in clinical work.

It will be remarked that r, by this solution, is the radius of a circular arc whose chord measures 3 mm. which arc is assumed to be of the same curvature as a section of the corneal surface by a plane passed through the visual axis and the axis of the telescope. But the configuration of the cornea is approximately that of a segment of a prolate ellipsoid, and supposing the axis of this ellipsoid to coincide with the axis of the telescope, r will be the radius of a circle whose curvature is equal to that of the elliptical section of the cornea at the two points in which the direction of the reflecting surface determines the length of the image, *i.e.*, at two opposite points on the ellipsoid each 1.5 mm. distant from its axis. Under these conditions it is evident that r will be greater than the radius of curvature of the cornea at its centre.

As a rule, the visual axis does not coincide with the axis of the corneal ellipsoid, but makes an angle with it (angle α), which angle is sometimes as great as 12°. The axis of curvature of the cornea is, therefore, not ordinarily in a line with the axis of the telescope, and the two points in which the direction of the corneal surface determines the length of the image are not symmetrically placed with reference to the axis of the ellipsoid. As the curvature of the ellipsoid at these two unsymmetrical points is unequal, it cannot be represented by a spherical surface. In any case, however, the value of r by equation (4) is greater than the radius of curvature of the cornea at its centre.

consequently r (the radius of curvature of the cornea) is an inverse function of the chord $M\,M'$. The length of this chord is read from the graduation on the arc. The radius of curvature of the cornea in different meridians

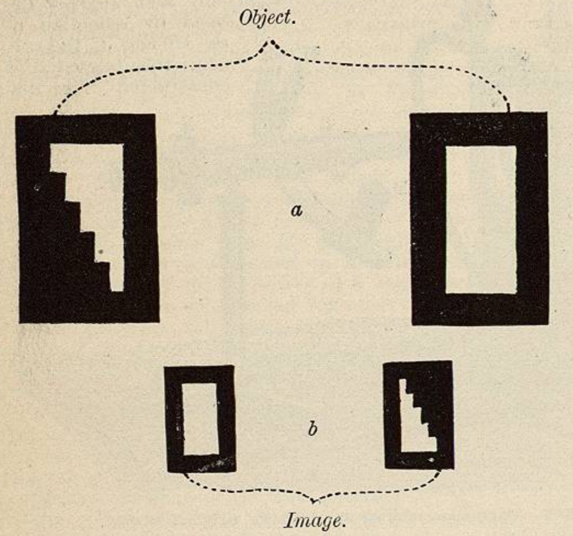

FIG. 3638.—*a*, The Targets; *b*, their corneal images as seen through the telescope without intervention of the prism of Iceland spar.

may be calculated from measurements of the chord $M\,M'$, made after turning the telescope, with the arc and targets, about its axis.

The great value of the Javal-Schiötz ophthalmometer is in its remarkable adaptation to the detection and measurement of corneal astigmatism, and for such examination it has won general recognition as indispensable to the ophthalmic practitioner. In astigmatism the essential thing to be considered is the difference in refraction in the two principal meridians, and it is for the measurement of such differences in the corneal curvature that the instrument has been especially designed. In the use of the ophthalmometer the length of the object (chord $M\,M'$) remains unchanged throughout the observation of the eye in its two principal meridians, and it is only the difference in the length of the image when the arc is adjusted successively for the corneal meridians of greatest and least curvature that is regarded. The observation consists in simply noting the amount of overlapping of the two images in the second position of the arc, after having first brought them into exact contact in the first position.

The device for reading the amount of overlapping of the images is shown in Fig. 3638, *a*. The outer side of one

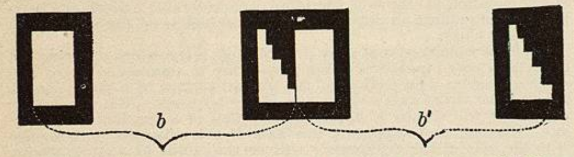

FIG. 3639.—Corneal Images as Seen Through Telescope and Prism. Double images in touching position.

of the rectangular targets is cut in the form of steps of such width that each step approximately represents a difference of corneal curvature corresponding to 1 D of ocular refraction.* The number of overlapping steps is taken as the number of dioptries of astigmatism attributable to inequality of curvature of the cornea in its two principal meridians.

Fig. 3639 shows the doubled images of the targets in the position of contact; in Fig. 3640 the same images are shown with two steps overlapping, indicating 2 D of corneal astigmatism. It will be observed that in both these positions the images are rectangular, also that they lie exactly in the same line.

This rectangular form and linear direction of the images of the four targets is seen whenever the curvature of the cornea is symmetrical with reference to the plane of the arc. When the cornea is a surface of revolution, with its axis passing through the centre of the arc, this condition is fulfilled for all positions of the targets; but when the cornea is of a configuration approaching an ellipsoid of three unequal axes, the position of the arc

FIG. 3640.—Overlapping of Double Images — As = 2 D.

must be such that its plane shall bisect the ellipsoid in one or the other of its two principal planes. In all other positions of the arc the images of the four targets appear more or less distorted, and the images of the two pairs of targets are not in the same line (see Fig. 3641).*

This distortion and oblique displacement of the two images, in all but two positions of the arc, reveals at a glance the presence of corneal astigmatism. To find the meridian of greatest corneal curvature, the arc is turned until the images are seen in a line and most widely separated.† The two targets are then moved inward or outward on the arc until the images are brought into the position of contact. Lastly, the arc is turned through an angle of 90°, or until the images are again seen in a line, and the number of overlapping steps, which repre-

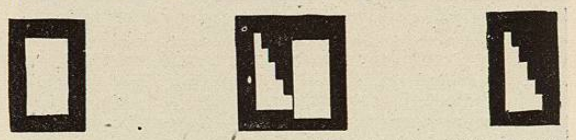

FIG. 3641.—Double Images not on a Level—Astigmatism Present. Arc not in a principal meridian.

sents the number of dioptries of corneal astigmatism, is noted. The examination of the two eyes need not consume more than two or three minutes.

The measurements of corneal astigmatism as made with the ophthalmometer agree remarkably, in most cases, with the results obtained by the use of methods which show the total astigmatism of the eye. The agreement in the direction of the principal meridians is especially close, so that in by far the greater number of cases the direction of the axis of the correcting cylindrical glass may be taken directly from the reading of the instrument. In respect to the grade of astigmatism the agreement is less exact, for the reason that the observed corneal astigmatism is often modified by an astigmatism attributable to an oblique position of the crystalline lens. As a rule, the meridian of greatest corneal curvature is

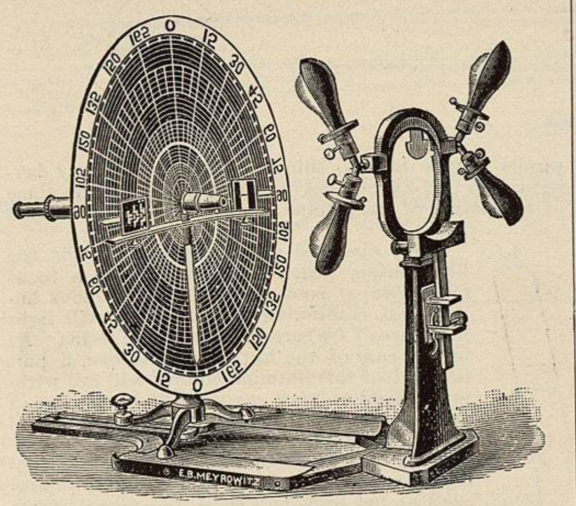

FIG. 3642.—Javal's Ophthalmometer with Attachment for Electrical Illumination of the Targets.

approximately vertical, and the meridian of greatest lenticular refraction is approximately horizontal; the total astigmatism is therefore generally somewhat less than the corneal astigmatism when the meridian of greatest corneal curvature is approximately vertical, and greater when, contrary to the rule, it is approximately horizontal.

In a comparatively small number of instances the total astigmatism is found to vary very widely from the corneal. For example, a relatively high grade of lenticular astigmatism may so far dominate a corneal astigmatism as largely to control both the direction of the principal meridians and the grade of the total astigmatism. Again, it is not uncommon to find a low grade of astigmatism, oftenest with the meridian of greatest refraction horizontal or nearly horizontal, in the absence of corneal asymmetry. Lastly, the ophthalmometer occasionally reveals an anomalous condition in which the corneal meridians of greatest and least curvatures are not at right angles to each other.

Not only has the Javal-Schiötz ophthalmometer greatly advanced our knowledge of astigmatism, but it affords, also, most important special information in every case of investigation of the refraction of the eye.

The instrument-maker Kagenaar (Utrecht, 1887)[11] has somewhat cheapened the original Javal-Schiötz ophthalmometer by substituting a pair of weak glass prisms, turned in opposite directions, for the doubly refracting prism of Iceland spar. Leroy and Dubois (1888)[12] have also produced a low-priced ophthalmometer, in which the doubling of the image is effected by means of two plates of thick glass as used by Helmholtz. In a second and newer model[13] (see Fig. 3642) the shape of the targets has been somewhat altered; and the direction of the meridians of greatest and least corneal curvature is read on the reflected image of the darge disc which now constitutes the most conspicuous feature of the instrument.

Carl Koller.

* Inasmuch as different eyes present considerable variation in corneal curvature, necessitating a corresponding variation in the separation of the targets in order to bring their images into exact contact, it is evident that a step on the target does not always represent the same fractional part of the chord $M\,M'$. In the case of a relatively flat cornea the targets must be set nearer together, and each step will then represent a larger fractional part of the chord $M\,M'$; conversely, when the cornea is of greater than average curvature the targets must be set wider apart, and each step will then represent a smaller fractional part of the same chord. It follows that in the former case each overlapping step in the image must represent somewhat more, and in the latter case, somewhat less, than 1 D of corneal astigmatism. It is well, therefore, always to note the length of the chord $M\,M'$, so that a correction can be made for it if deemed necessary.

* For an analysis of the phenomenon of distortion of the image formed by a mirror of asymmetrical curvature, also of the same phenomenon as it occurs in the case of a lens of asymmetrical refraction. see a paper by the writer: "Ein Beitrag zur Theorie der Cylinderlinsen," Graefe's Archiv, 1887.

† By interchanging the targets the images may be brought into the position of contact when the arc is set in the meridian of least corneal curvature, and the overlapping steps counted in the second position of the arc; in practice this is found to be more convenient, for the reason that the meridian of least curvature is, as a rule, approximately horizontal, and it is easier to adjust the targets in the horizontal and to observe the overlapping of the images in the vertical meridian.

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OPHTHALMOSCOPE; OPHTHALMOSCOPY,—from *ὀφθαλμός*, eye, and *σκοπέω*, to view. The ophthalmoscope, German, *der Augenspiegel*, is an optical device by means of which the interior of the eyeball is rendered visible.

Ophthalmoscopy, in its wider meaning, includes whatever pertains to the objective examination of the eye; in a narrower sense, it is restricted to the examination of the interior of the eye by the aid of the ophthalmoscope.

The anterior segment of the eyeball, comprising the cornea, the anterior chamber filled with the aqueous humor, the front of the iris, and so much of the anterior capsule of the crystalline lens as corresponds to the area of the pupil, is accessible to direct inspection by the naked eye, or through a magnifying glass. Even when the pupil is strongly contracted, a central opacity of the

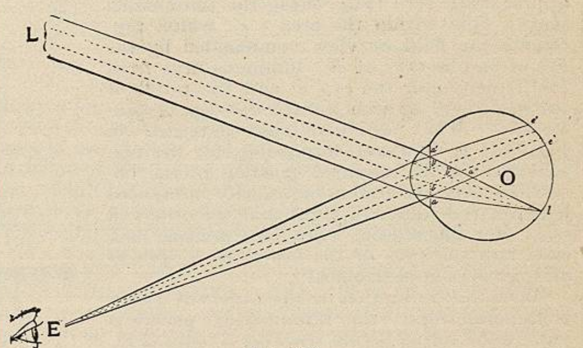

FIG. 3643.

lens capsule or of the immediately subjacent lens substance reveals itself by a characteristic white or gray appearance. When the pupil is widely dilated, we may look deeply into or through the crystalline, and may obtain glimpses of a detached and displaced portion of the

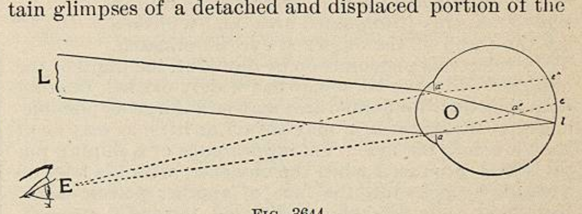

FIG. 3644.

retina, of a blood clot or other large foreign body in the vitreous, or of the surface of a very prominent tumor arising from the retina or choroid.

Let *L* (Fig. 3643) represent a pencil of parallel rays emanating from a distant source of light and entering the dilated pupil $a\,a'$ of the eye O, so as to light up a

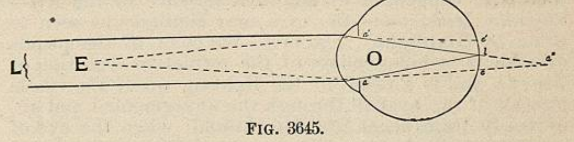

FIG. 3645.

path through the vitreous, indicated by the cone $a\,a'\,l$. The eye of an observer at E will receive rays from any object which may happen to lie within that portion of this cone, near its base, which is bounded by the line $a\,a''$. Outside of the limits $a\,a'\,a''$, the whole interior of the eye is either in comparative darkness or is shut off from view by the iris at a, a'. If the pupil is contracted