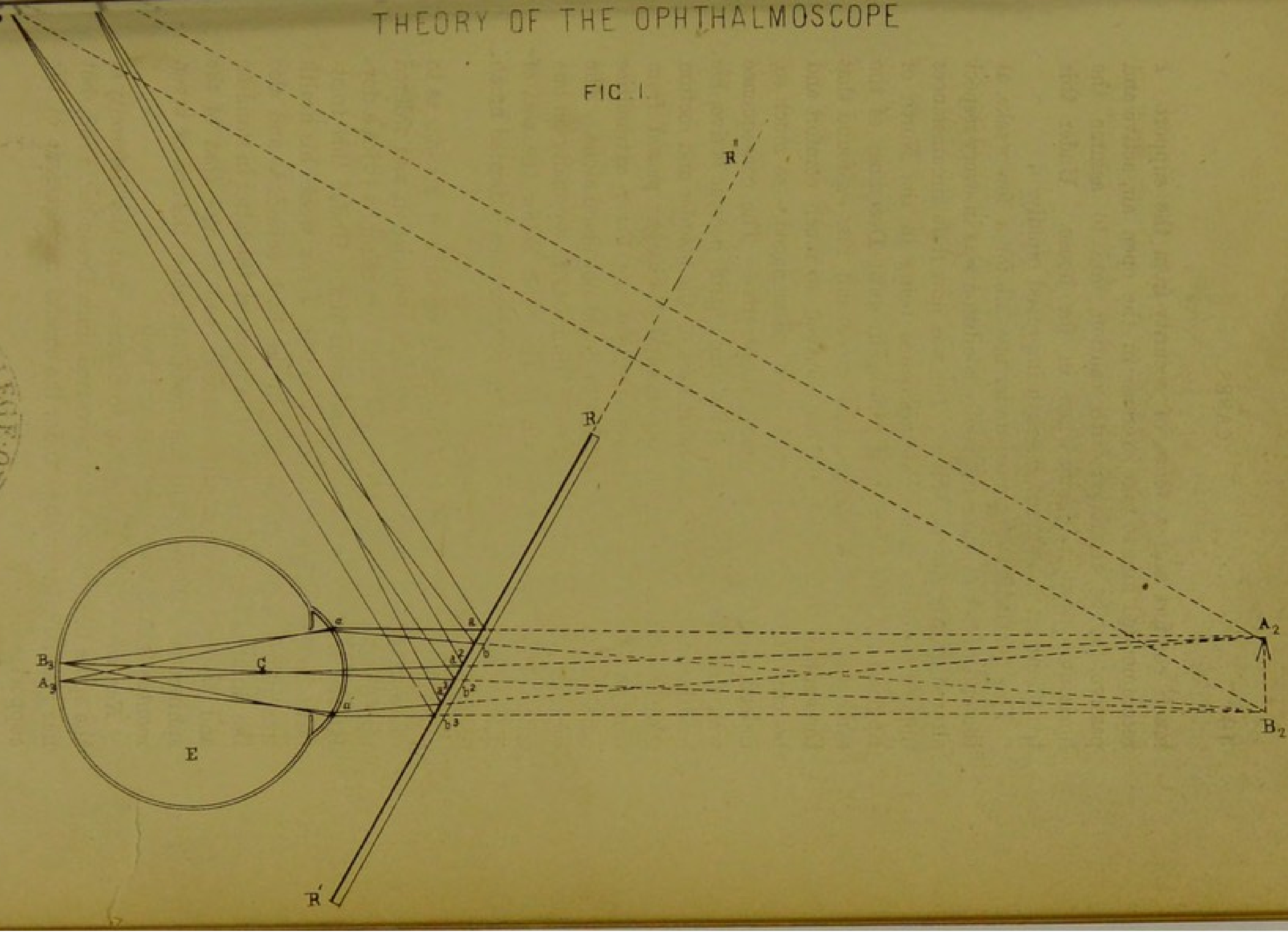
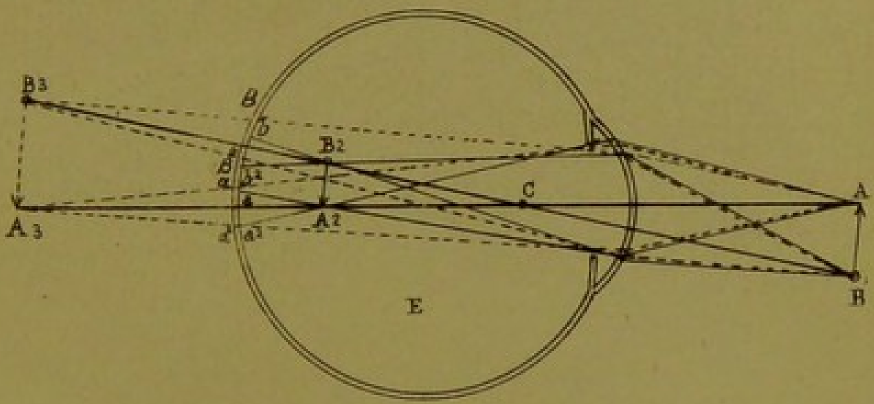
THEORY OF THE OPHTHALMOSCOPE

FIG. I.



THEORY OF THE OPHTHALMOSCOPE

FIG. V.



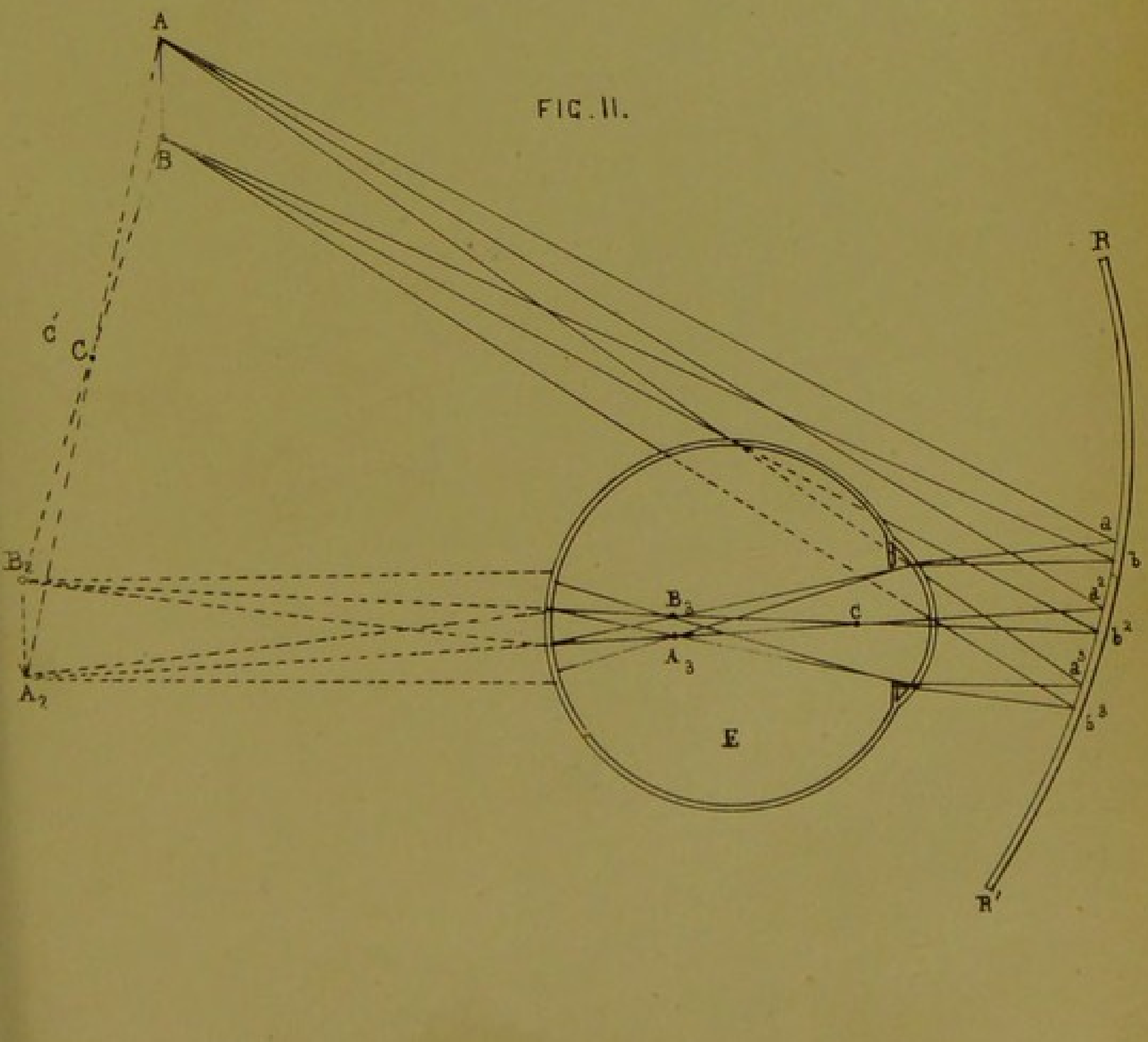
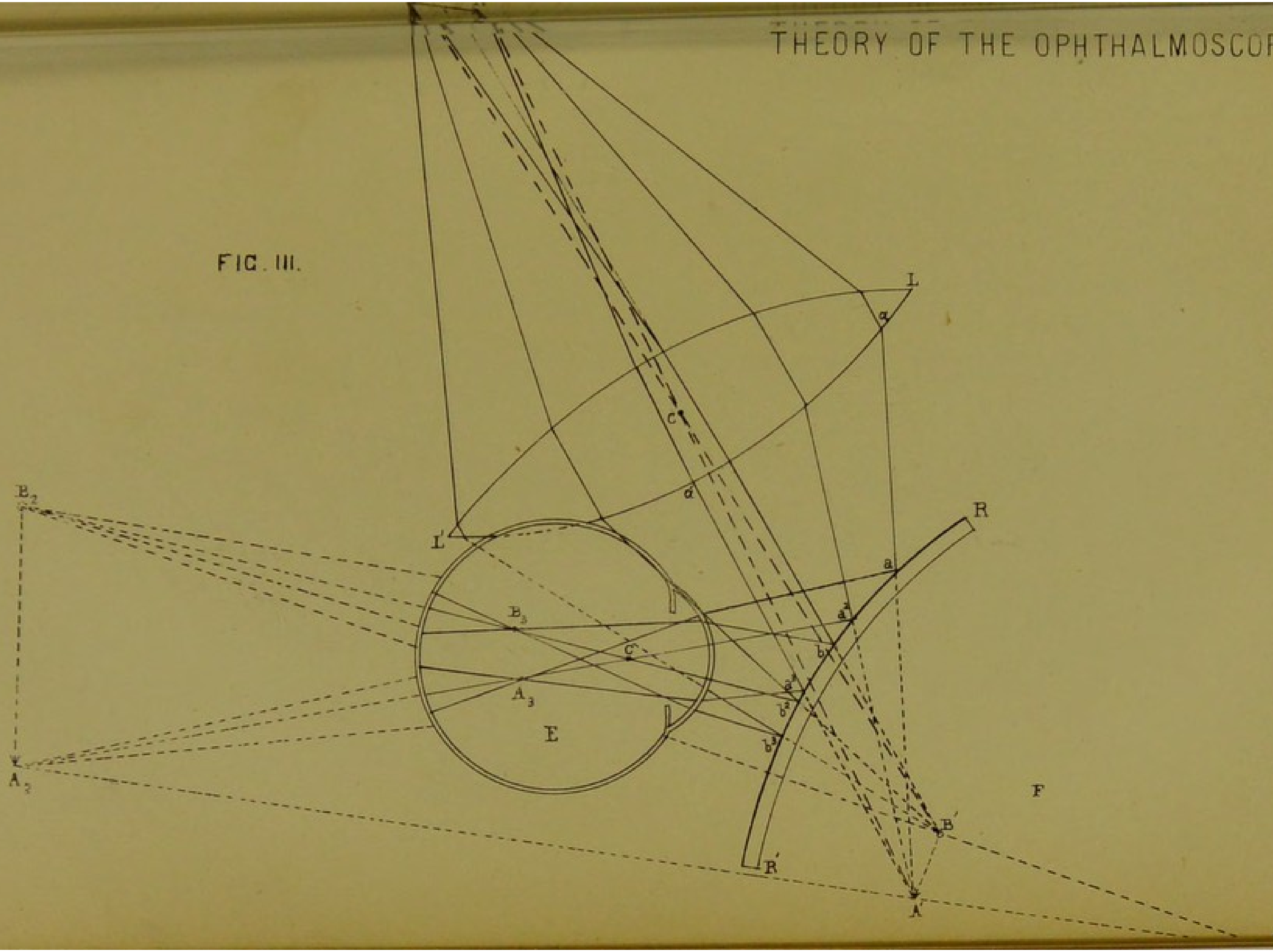


FIG. II.

FIG. III.



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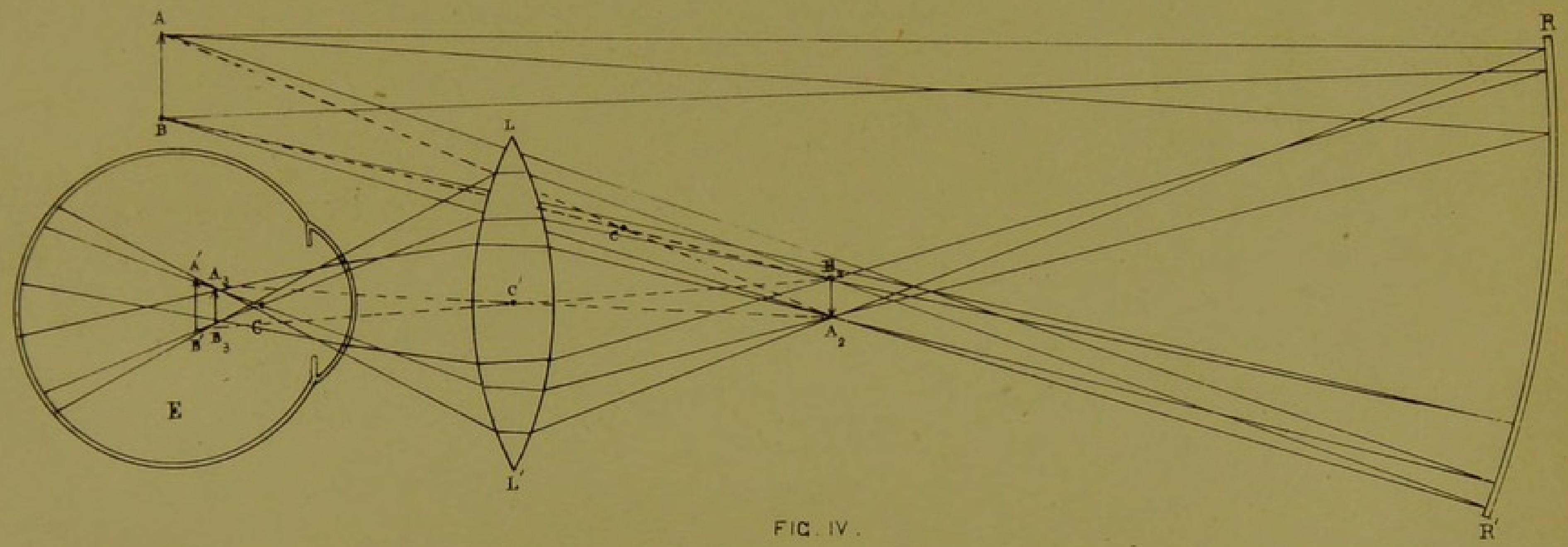


FIG. IV.

FIG. VI.

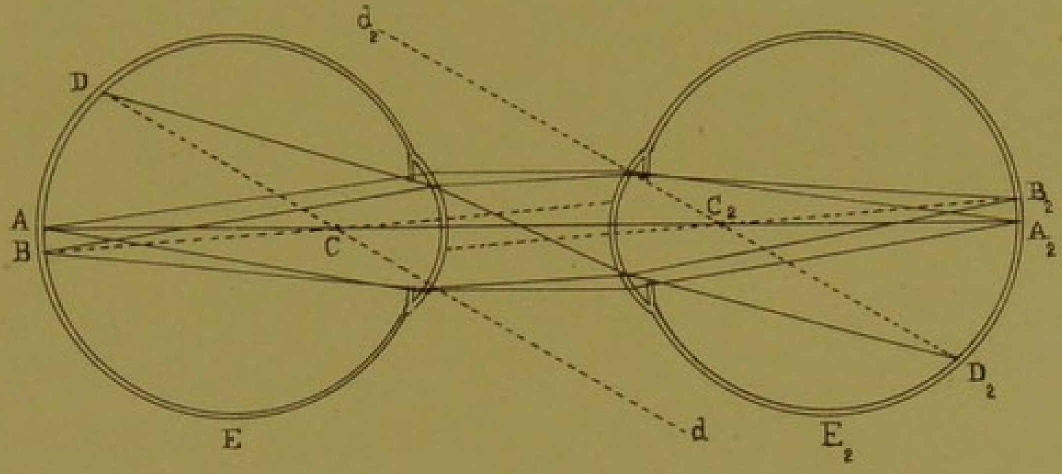
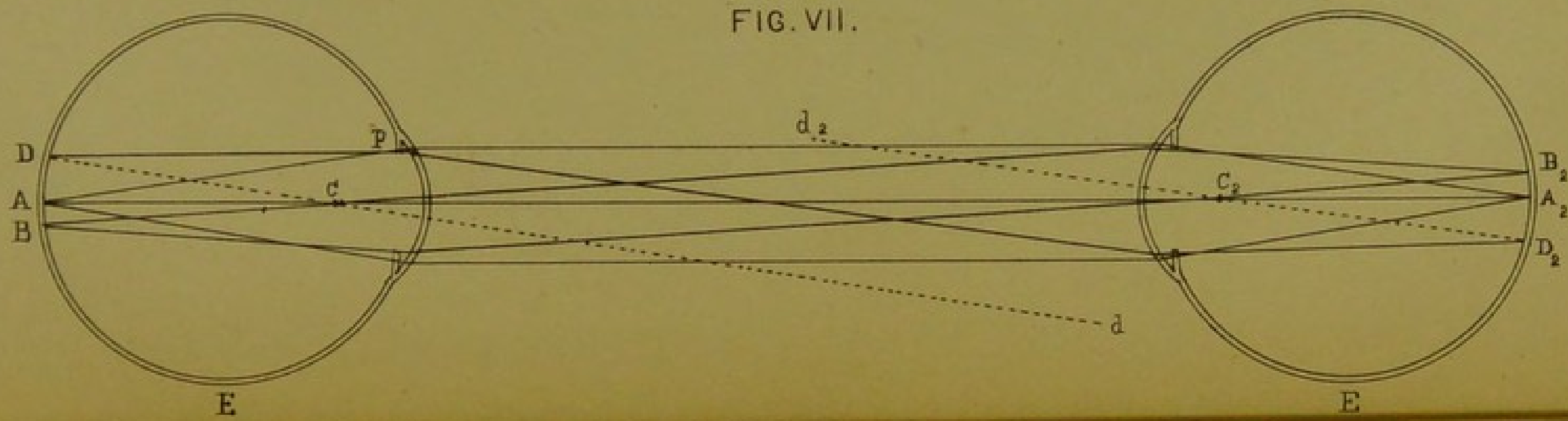


FIG. VII.



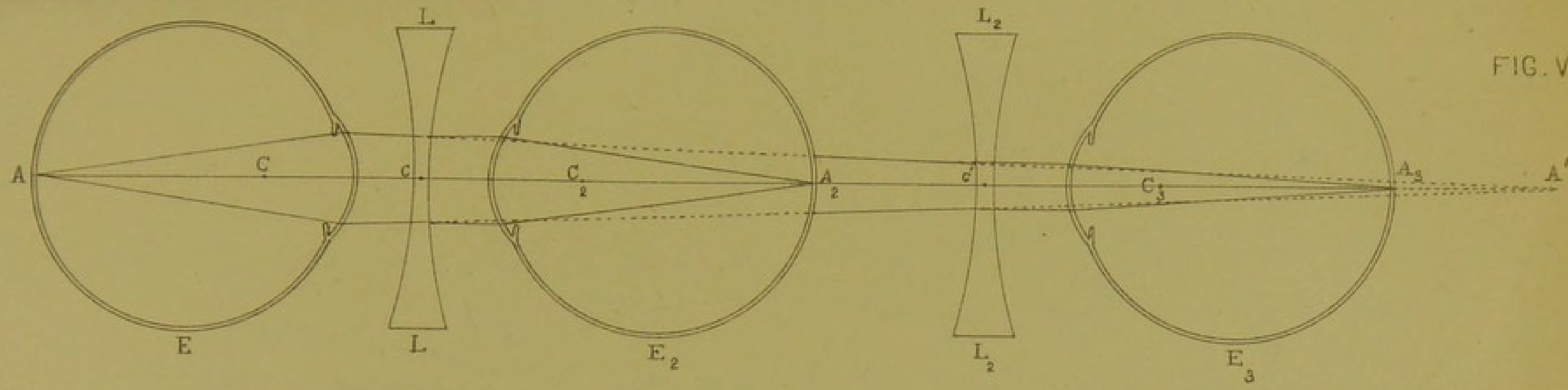


FIG. VIII.

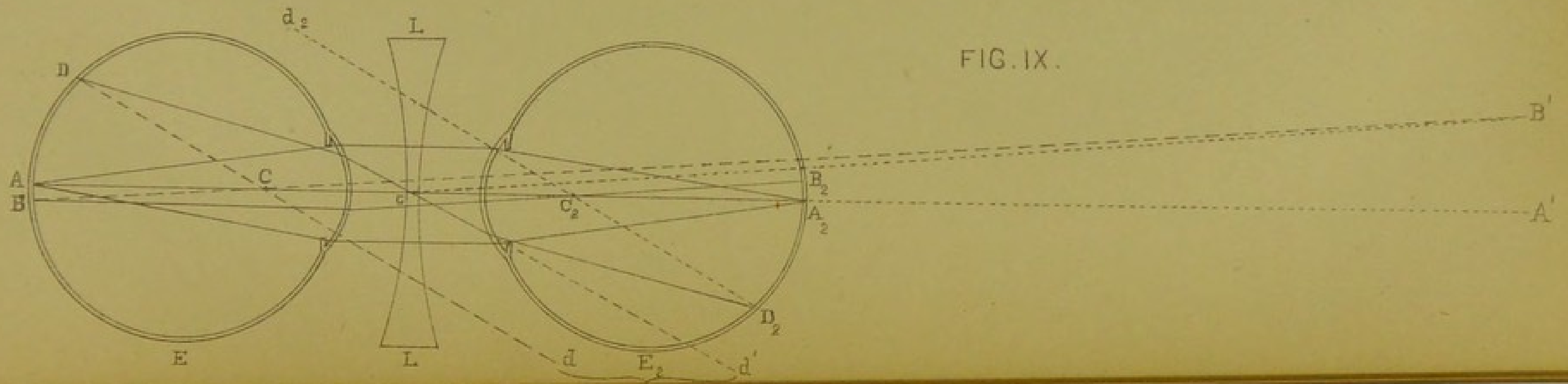


FIG. IX.

FIG. X.

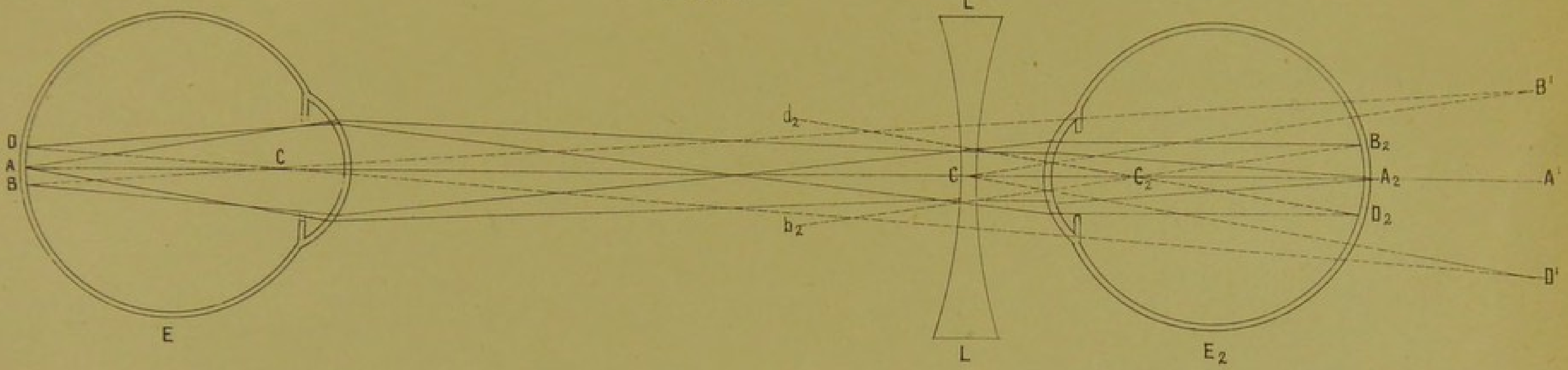


FIG XI

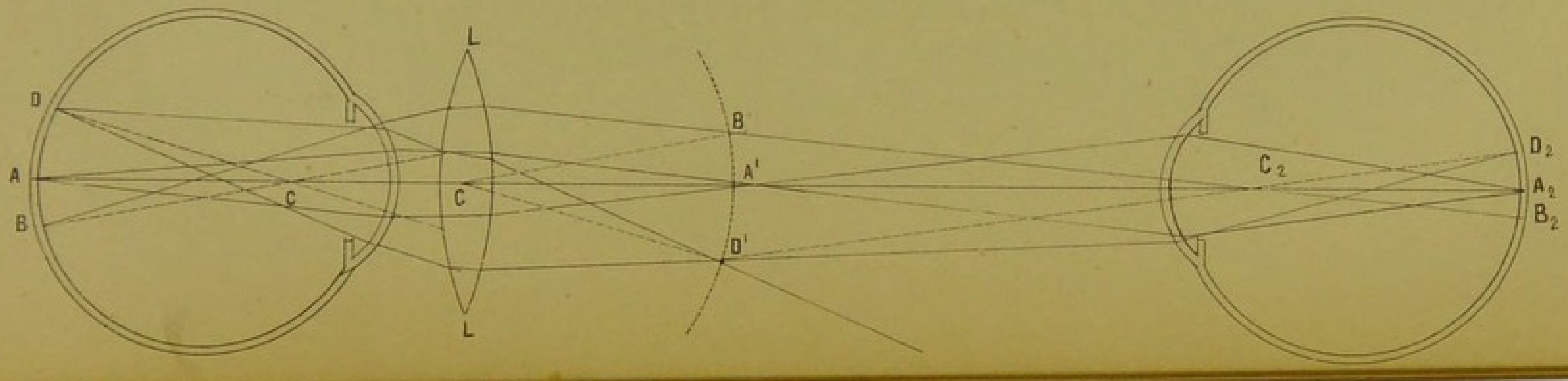


FIG. XII.

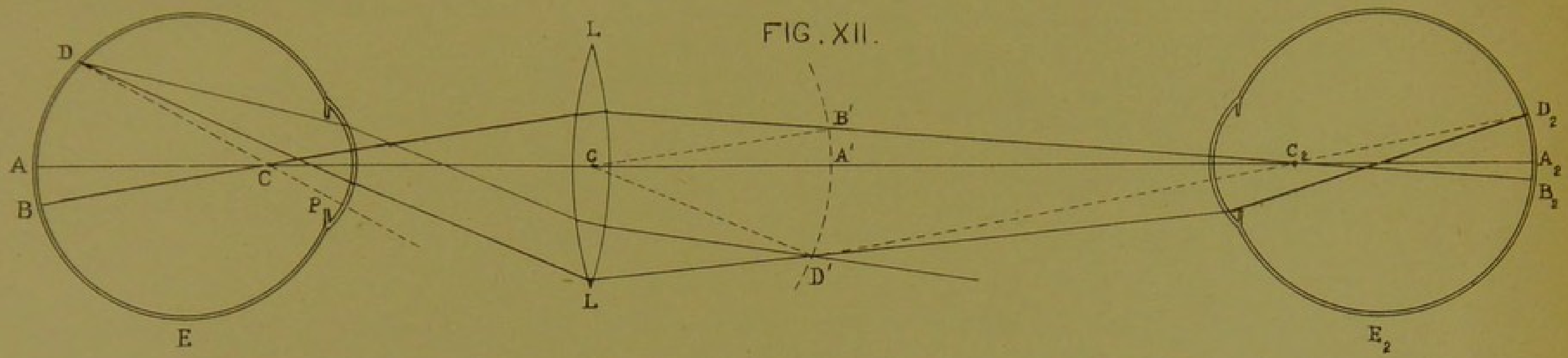


FIG. XIII.

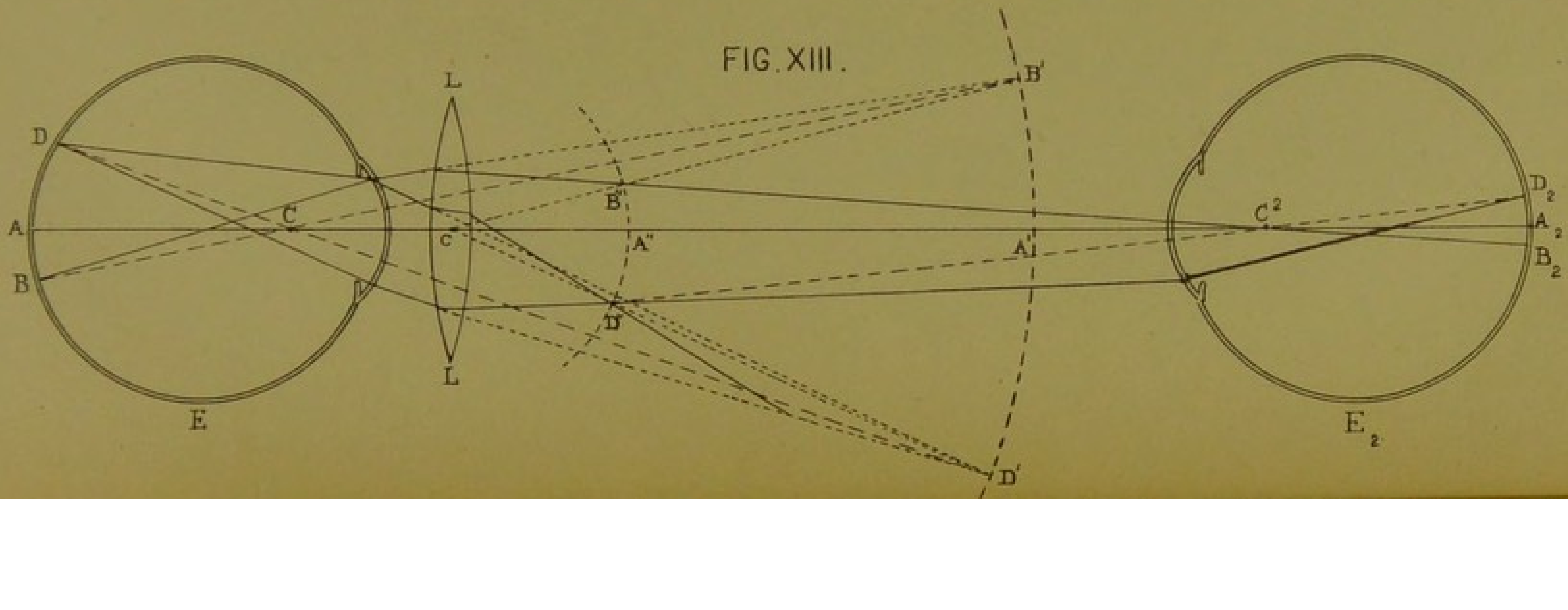


FIG. XIV.

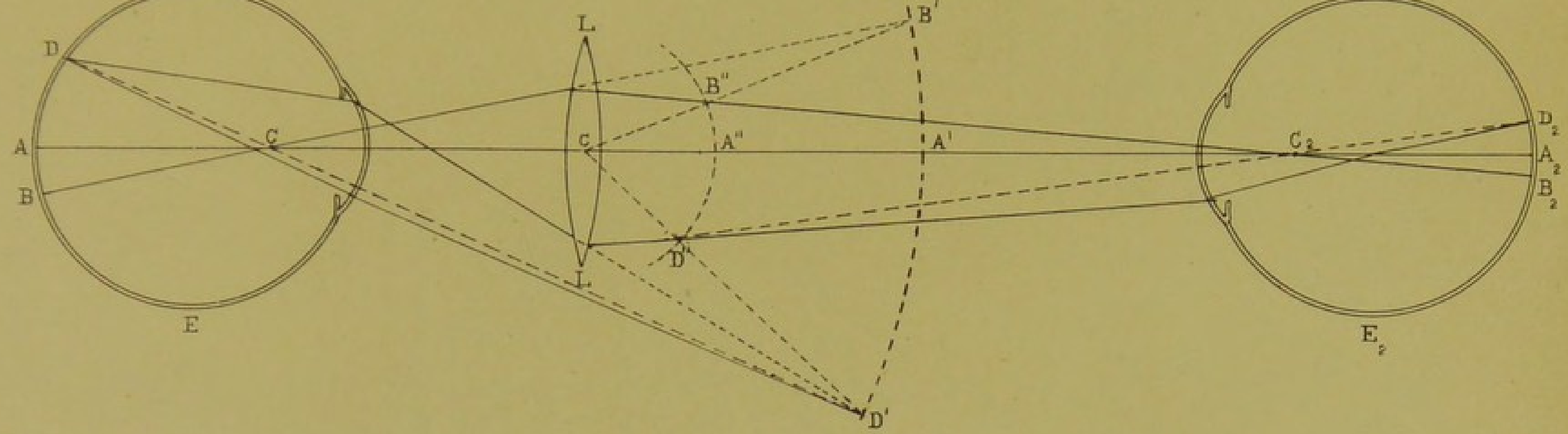
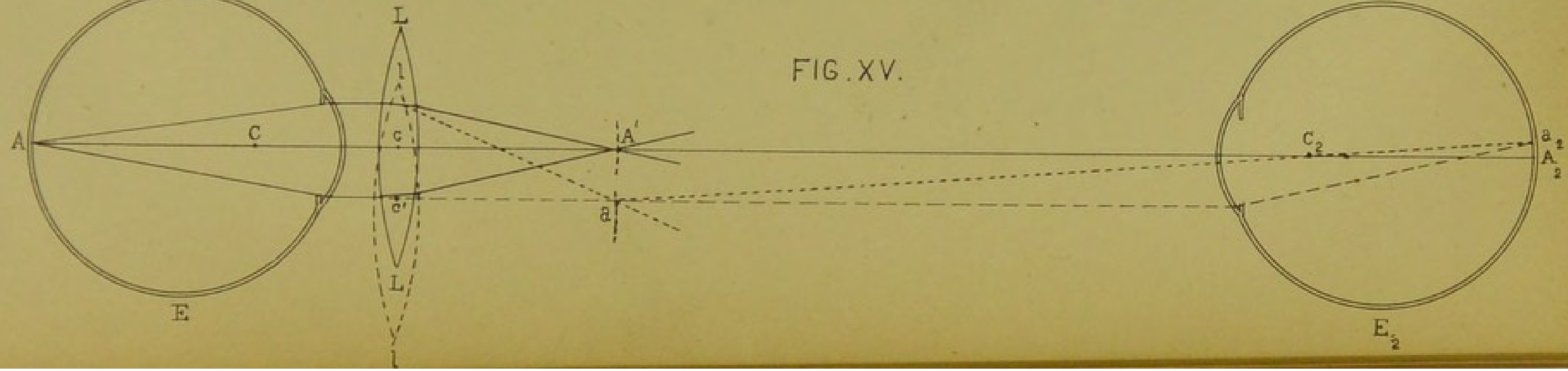


FIG. XV.



ON THE THEORY

OF THE

OPHTHALMOSCOPE.

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ON THE

THEORY OF THE OPHTHALMOSCOPE.

Part I.—INTRODUCTORY REMARKS.

It has long been known that, when certain conditions are fulfilled, a visible reflection takes place from the deep-seated parts of the eyes of some animals, and even of the human eye in certain abnormal states; so that the pupil assumes a luminous aspect, and a yellowish or pinkish colour, instead of appearing black. But it is only of late years that the knowledge of this fact has been turned to any practical advantage, and that the possibility of obtaining a distinct view of the deep-seated parts of the living eye in detail—demonstrated on the eye of the cat by Méry in the beginning of the last century—has been brought to bear upon the diagnosis of disease in the human eye, and upon the advancement of our knowledge of its physiology.

A view of objects situated at the fundus of any eye, the refracting media of which possess a certain degree of transparency, may be obtained by the use of the ophthalmoscope properly handled; but almost every beginner finds considerable difficulty in managing his instrument so as to obtain the desired result, and finds much greater difficulty in the examination of some eyes than in that of others, without his being able to assign a satisfactory reason for the difference.

In order that an observer may see any object distinctly, it is necessary that light coming from points on its surface should enter his eye in sufficient quantity, and that the rays coming from any given point of the object, and striking upon his eye, should do so in such a manner that they may be brought to a focus on the retina after they have passed through the refracting media.

The quantity of light which may be required depends, not only upon the acuteness of the observer's vision and upon the absolute intensity with which the object is illuminated, but upon the relation which subsists between its brilliancy and that of surrounding objects.

Every one knows the difficulty of seeing the interior of a chamber lighted by a small aperture, when it is looked at from the outside, even though the chamber may appear well lighted to those within it. Thus, if we attempt to look through the window of a room from the other side of the street, we find it difficult to see the opposite wall of the room, because each point on its surface, instead of having light falling upon it from every direction, as it would have if it were in the open air, is illuminated by a cone or pyramid of light, the apex of which coincides with the point in question, while its angle is determined by the size of the window and the depth of the room. If the room is lined with a dark-coloured paper, the difficulty of seeing even light-coloured objects within it will be greatly increased; because, while their direct illumination is still faint in comparison with that of objects outside the house, they derive very little additional brilliancy from light reflected about from one wall of the room to another.

Several circumstances of the kind just mentioned combine to render it almost impossible to see objects on the retina of the living human eye in ordinary cases; but there are others still more important, which must be taken into account in devising the means of overcoming the difficulty.

It is obvious that if the aperture by which a chamber is illuminated is small in proportion to the depth of the chamber, an observer will not see a point on its opposite wall, unless his eye is pretty nearly in line with the point and with the external source of the light; because the whole light which goes through the aperture and falls upon the point, and the whole light which passes through the aperture on its return from the point, are both confined to the same narrow conical space, limited by the angle which the aperture subtends at the point in question. If the observer's head is much larger than the aperture, he will find it difficult to place himself at any convenient distance nearer the aperture than the source of light is, so that light from the point which he wishes to see may enter his eye, without shutting off all the light from the interior of the chamber; while, if he places the source of light between himself and the aperture, his own eye will be dazzled. All this applies to the examination of the human eye; but the most important obstacle which we have to overcome is to be found in the refracting properties of the eye under examination.

It is always difficult to see objects situated nearly in the principal focus of such a dioptric apparatus as the eye, when they are both illuminated and seen by means of light which has passed through the refracting media.

Let E (fig. 1) represent an eye; let the dart, $A_2\,B_2$, represent the flame of a lamp or candle placed opposite to it; and let the eye E be accommodated for the distance of the flame.* All the light which comes from the point A^2, and enters the eye E will be brought to a focus at the point A_3; and no light from other parts of the flame will fall upon the point A_3. All the light which is reflected from A_3, and which emerges from the eye will, according

* The other parts of the diagram may be disregarded at present.

to optical principles, return to A_2, where the rays will cross each other. The light returning from the point A_3, and the light going to A_3, will accordingly be confined to a space limited by the lines A_2a, aA_3, A_3a', and $a'A_2$, and which we may regard as occupied by two luminous cones united at their base, which is very little wider than the pupil of the eye E. Now, if an observer were to place his eye in any part of the space above mentioned, his head would shut off all the light proceeding from the point A_2 to the point A_3; and if he placed himself to one side of the luminous cone, none of the light returning from the point A_3 would enter his eye. He might, no doubt, retire behind A_2, and some of the light from A_3 might then enter his eye after the rays had crossed each other in A_2; but, in this case, he would be dazzled by the flame itself, and he could not place a screen between the flame and himself, without shutting out from his own eye all the light which had returned from the point A_3 and passed through the point A_2. The same thing would hold good of any point on the retina of the eye E.

If the eye E were not adjusted for the distance of the flame, the light from the point A_2 would not be all concentrated upon the point A_3; but it would be distributed over a space of nearly circular form, having its centre nearly in A_3. In like manner, the light from B_2 which would enter the eye E would be distributed in a circle round B_3; and, if the circle were large enough, some of the light from B_2 might fall upon A_3.

All the light reflected from A_3 and returning directly through the pupil will, after emerging from the eye, proceed to a point very nearly in the line A_3 A_2, or in a continuation of that line beyond A_2; or else, if the eye is abnormally presbyopic, it will diverge as if it radiated from a point behind A_3, in the continuation of the line A_2 A_3. In this case, it may still be impossible for an observer to place his eye nearer to the eye E than the flame is, and in such a position that any of the light from the point A_3 may enter it, without shutting off from the eye E all the light from the point A_2; but he may be able to do so without shutting off the light which goes to A_3 from such points as B_2, and thus he may see the reflection from points on the fundus of the eye E.

Again, he may go behind the flame and place a screen between it and his own eye, without intercepting all the light reflected from such a point as A_3 before it reaches his eye, because some of the light so reflected does not pass through any part of the flame, but passes over above it.

It is practicable, in the manner last mentioned, to see a reflection from the deeper parts of the human eye; but still there is considerable difficulty in managing the matter satisfactorily, and there would be little use in merely seeing a reflection from the fundus of an eye, unless the rays coming from particular points in the eye observed could be brought accurately to foci on the observer's retina, which, in most cases, would be out of the question, if no other means were employed than those already indicated.

The problem now before us is, to place the observer so that his eye will be nearly in the axis of the cone of light emerging from the eye under examination, so that no part of his person will intercept the light on its passage from its source to the eye observed, and so that he will be shaded from the direct light of the flame; and, at the same time, to modify the direction of the rays which pass from the one eye to the other, so that they will ultimately be brought to foci on the observer's retina.

This problem was solved by Helmholz, who placed a bundle of glass plates, having their surfaces parallel to one another, in a position similar to that of the reflector RR', in figure 1; so that straight lines drawn from the centre of the reflector through the centre of the flame AB, and through the centre of the pupil of E, the eye under examination, would make equal angles with the reflecting surface. Light coming from such a point as A in the flame, and included between the lines Aa and Aa_3, will be partly reflected at the surfaces of the glass plates, and sent to A_3, on the retina of E, and part will pass through the glass. Light reflected from A_3, and thrown out of the eye E, will again strike the reflector, and part will be reflected towards A, while part will pass through the glass and go towards A_2. If the observer places his eye behind the reflector, and between A_2 and A_3, some of the light from A_3 will enter it; and he may screen himself from light coming directly from the flame AB, by having his glass plates framed obliquely in the end of a short tube through which he looks at the eye E. In the case represented in fig. 1, an observer so placed would see the reflection from the interior of the eye, E, but he would not see the details of the fundus oculi distinctly, because the rays from each point, such as A_3, are converging when they fall upon his eye, and would be brought to foci in front of his retina. This is remedied by placing an appropriate lens in front of the observer's eye, so as to change the convergence of the rays into divergence. The lens may be made to fit into the tube already mentioned; and we have now an instrument similar in its more essential particulars to the ophthalmoscope of Helmholz.*

Various improvements and modifications of the ophthalmoscope have been produced since its first invention; but they all resemble the original one in their most important part—viz., a reflector of some sort, through the centre of which the observer looks at the eye which he wishes to examine. And the first thing to be learned in using any ordinary ophthalmoscope is to hold it so

* Helmholz-Beschreibung eines augen-spiegels: Berlin, 1851.

that some part of the area on the fundus oculi under examination, which is illuminated by light coming from the reflector, shall be in line with the pupil of the eye observed, and with the pupil of the observer's eye. This is comparatively easy when the illuminated area is large, and it is more difficult when it is small; but it can always be attained by moving the instrument slightly, so as to alter the angle at which the reflecting surface is inclined to the eye of the patient, and to the flame of the lamp. When the observer has caught sight of the reflection from the fundus of the patient's eye, he will soon learn by practice to direct the light upon the particular parts which he may wish to examine, either by altering his own position and that of the ophthalmoscope, or by directing the patient to look at various objects in different parts of the room successively.

After the observer has acquired the power of thus illuminating the patient's eye, he will find that a great many circumstances have to be attended to, in order that he may at once illuminate a sufficiently large portion of the patient's retina, that he may see the objects so illuminated distinctly, and that he may be able to interpret what he sees correctly. A knowledge of these circumstances may, no doubt, be arrived at empirically, if one has extensive opportunities of making ophthalmoscopic examinations of different healthy and diseased eyes; but it is always of importance—if not always absolutely necessary—that those who make use of optical instruments should have some knowledge of the leading theoretical principles which have a bearing on their construction and application to the purposes for which they are employed.

This remark applies very specially to the use of the ophthalmoscope; because, while the optical relations are somewhat complicated, the employment of adjustive mechanism is generally inconvenient, from the circumstance that the eye of the patient, which is often unsteady, forms part of the instrument. Under these circumstances, it will be found that many sources of difficulty and error may be obviated, not only by a knowledge of optical principles in the abstract, but by a reference to their practical application to the case in hand.

The desideratum last mentioned is the one most frequently found wanting; for it is not uncommon for those who have some knowledge of the elementary principles of optics to fall into considerable perplexity when called upon, for the first time, to apply that knowledge to a new mode of investigation, involving the use of instruments, natural and artificial, the optical properties of which have not been studied in their relation to the peculiar circumstances under which the investigation is conducted.

In the course of the following remarks I propose, first of all, to make a brief statement of some leading optical facts which must be taken into account by those who wish to make an intelligent use of the ophthalmoscope; and then I shall endeavour to point out the application of these facts to the various circumstances under which ophthalmoscopic examinations are generally conducted. If, in doing so, I should seem to enter rather too minutely into the consideration of certain subjects with which the reader is already familiar, it must be remembered that much future explanation may be saved by our having some definite starting point, and that misunderstandings may be avoided if I do not require, in the course of subsequent observations, to pre-suppose a knowledge on his part of any important fact which has not been previously brought under his consideration.

Definitions, &c.—Before proceeding further, it may be as well to state that, by a *focus*, we are to understand a point in which the lines of direction of a set of rays intersect one another; whether the rays themselves actually meet in that point or not. In the former case the focus is termed a *real*, and in the latter an *imaginary* one. Thus, the point A (fig. 1) is the real focus of the rays Aa and Aa_3 which proceed from it to the reflector RR′; the reflected rays a*a* and a^3a' have an imaginary focus at A^2, where their lines of direction intersect one another; and the rays aA_3 and $a'A_3$, which have been refracted at the eye E have a real focus in A_3.

Rays falling upon a given surface are said to be *incident* upon it. A set of rays having a common focus, or having their lines of direction parallel to one another, is termed a *pencil* of rays; and such pencils may of course be regarded as incident, or reflected, or refracted, when considered with reference to some surface on which they are incident, or at which they are refracted or reflected; so that it may be necessary to speak of the same pencil as a reflected or refracted one at one time, and as an incident one at another, according to its relation to the particular surface which may be under consideration. Thus, the pencil to which the rays a*a* and a^3a' in fig. 1 belong, is reflected at the surface RR′, and incident on the cornea of the eye E.

The term *axis*, when employed in speaking of pencils of light, is used in different senses by different writers on optics. Strictly speaking, it ought to be applied only to a straight line which coincides with the line of direction of the middle ray of the pencil; but some writers understand by the term *axis* of an incident, reflected, or refracted pencil, a straight line drawn from the focus of the rays composing the pencil at right angles to the surface on which they are incident, or at which they are reflected or refracted. When the rays of a pencil are parallel to one another, the axis of the pencil, in this sense of the term, is a line drawn at right angles to the surface, and parallel to the direction lines of the rays composing the pencil, the focus of which is regarded as a point at an infinite distance from the surface. In either case, the term is applied to a line which may or may not be the geometrical axis of the pencil itself, but which is the axis of a larger imaginary pencil of which the real one forms a part.

In referring to the *axis* of a pencil of light, I mean to use the term in the latter of the two senses given above; because it is a short and convenient name for a line to which repeated allusion will be made in the following pages. If it should be necessary to allude to the true *geometrical axis* of any pencil, due notice of the circumstance will be given.

The line AA_2, drawn through the continuation of the surface R′R, at right angles to it, is the axis of the pencil Aa, Aa_3, incident on the surface RR′, and of the reflected pencil aa, a_3a', when considered with reference to the surface RR′; while the line, A_2CA_3, drawn at right angles to the surface of the cornea of E, is the axis of the pencil, aa, a_3a', considered as incident on the cornea.

The axis of a reflecting or refracting surface is a straight line drawn through its centre at right angles to the surface.

A pencil of light, when regarded in connection with a reflecting or refracting surface, is termed a *principal* pencil, when its axis coincides with the axis of the surface; and a *secondary* one when it does not coincide with it.

Radiation and Transmission of Light.—Whatever theory may be adopted regarding the nature of light, we may affirm that light, radiating from points in a luminous body, is propagated through a given medium of uniform density in straight lines.

The quantity or amount of light which, radiating from a luminous source of given intensity, falls upon a surface of given dimensions, placed at right angles to the direction of the rays, is inversely proportioned to the distance between the source of the light and that surface.

Different substances have different powers of absorbing light in its passage through them; and they are regarded as transparent, semi-transparent, or opaque, with a reference to their capability of transmitting light. The distinction, however, must be taken as a comparative, and not as an absolute one; because the transparency or opacity of any body with which we are acquainted, depends upon the relation between the intensity of the light on entering it, and the distance which it has to traverse before emerging again; so that, if the light is faint enough, or the body thick enough, the whole of the former will be absorbed, however transparent the latter may be.

Particular kinds of light are absorbed or transmitted with much greater facility by some substances than they are by others. Thus, we may find that one substance transmits a large proportion of the blue rays, and absorbs a large proportion of the other rays, of which a ray of white light is composed; while another substance transmits the red rays and absorbs the rest.

Not only does the capability of transmitting different kinds of light vary much in the case of different substances; but one and the same substance may undergo changes in its state, subject to various physical or chemical conditions, which modify the light transmitted by it as to its quality and intensity, and even as to its distribution.

Reflection of Light from Unpolished Surfaces.—When light falls upon a rough surface, a certain portion of it is reflected; and in such a manner that it radiates from each point of the surface in all directions in which there is a transparent medium for it to radiate in, just as it would from points in an original source of light.

The quantity and quality of the light so reflected will vary according to those of the incident light, and according to the power of absorbing and transmitting particular kinds of light which the substance composing the reflecting body may possess. A substance which appears red by reflected light generally absorbs the greater part of the rays of other colours; and if it has a certain degree of transparency, it will appear red by transmitted light also. But this is not always the case, for certain substances have a property, termed diplochromatism, in virtue of which they reflect light of one colour, and transmit light of another colour. The crystalline lens of a glaucomatous eye, which appears to be greenish by reflected light, and yellowish-brown by transmitted light,* is an example that readily occurs in connection with our subject.

The apparent colour as well as intensity of the light reflected from or transmitted through different bodies, depends a good deal upon contrast. Black substances appear so in consequence of their absorbing a very large proportion of all the rays of the spectrum. On this account very little light is reflected from their surfaces, and they appear dark, especially when compared with other bodies similarly conditioned in other respects. That portion of the incident light which is reflected from black surfaces, is of a pale tint, being generally made up of a combination similar to that of which white light is composed. This may be observed by concentrating a strong light on a piece of black cloth by means of a condensing lens, when the illuminated part appears of a pale-greyish colour, as contrasted with the surrounding dark surface.

It will afterwards be seen that all these facts are of some importance, in connection with the interpretation of certain ophthalmoscopic phenomena.

Reflection of Light from Polished Surfaces.—If we trace the course of a ray of light emanating from a luminous point and falling upon a polished reflecting surface, we find that a portion of the reflected light, greater or less, according to the degree of polish which the surface possesses, is *regularly* reflected; that is to say, it is thrown off in such a direction that the angle of incidence—or the angle which the direction-line of the

* Mackenzie on the Diseases of the Eye, 4th edition, p. 895.

incident ray makes with a straight line drawn through the point of incidence at right angles to the reflecting surface—is equal to the angle which the direction-line of the reflected ray makes with the same perpendicular. It generally happens that a considerably greater proportion of light is regularly reflected when the angle of incidence is large, than when it is small. Some very imperfectly polished surfaces reflect a good deal of light regularly, when the incident light falls very obliquely upon them; and when light falls obliquely upon the surface of a transparent body, a large proportion of it is regularly reflected, which would be transmitted if the angle of incidence were less.

Plane Reflectors.—If we suppose the dart, A B, fig. 1, to represent the flame of a lamp or candle, and R R′, to represent a plane reflecting surface seen in section; and if the interrupted line, A A_2, is drawn at right angles to the reflecting surface, the angle of incidence of the ray, Aa, will be equal to the angle, aA A_2*, and the reflected ray aα will have its angle of reflection also equal to the angle a A A_2. This angle of reflection will also be equal to the angle A $A_2\alpha$ formed at the intersection of the perpendicular A A_2 and the line α a A_2, which is the direction line of the reflected ray aα, produced through a, so that A and A_2 are equidistant from the reflecting surface.

In like manner, the incident ray A a_3, and the reflected ray a_3 α', are inclined at equal angles to the perpendicular, A A_2; and from this it is obvious that the reflected rays, a α and a_3 α', are inclined to one another at an angle equal to that at which the incident rays A a and A a_3, are inclined to one another; and that the direction lines of the reflected rays a α and a_3 α', will meet in the point A_2, situated in the perpendicular A A_2, and as far behind the reflector as the point A is before it.

Similarly, rays which originally radiated from the point B will proceed after reflection at the surface R R′, as if they radiated from the point B_2; and an eye placed at E would see an erect image of A B in the position A_2 B_2.

The image A_2 B_2, is termed a *virtual* image, because it is made up of the imaginary foci of rays, which come in reality from the reflecting surface, but which seem to come from these imaginary foci.

If we now trace the course of rays coming from the point A_3, in the eye E, and modified in their direction at the refracting surfaces of the eye, we find that the rays α a, $\alpha'a_3$, which are incident on the reflector at a and a_3 have an imaginary focus towards which they are converging at A_2. The reflected rays a A and a_3 A, on the other hand, have a real focus at A; and if we consider the case of rays coming from points intermediate between A_3 and B_3, we find that they will be brought ultimately

* Euclid, B. I., prop. 29.

to real foci between A and B so as to form a *real* image which might be received on a screen at A B.

The following principles connected with regular reflection from plane surfaces may be deduced more or less directly from what has been already stated :—

1. The divergence, parallelism, or convergence of incident rays belonging to one pencil is retained after reflection.

2. The focus of an incident pencil and that of the corresponding reflected one are situated in a straight line drawn through the focus of the incident pencil at right angles to the reflecting surface, so that the incident and reflected pencil have a common optical axis.

3. The focus of an incident pencil and that of the corresponding reflected one are equidistant from any point in the reflecting surface, and they are on opposite sides of it.

4. The foci of an incident pencil and of the corresponding reflected one are reciprocal ; *i. e.*, if a point, which is the focus of a pencil of reflected rays, is at the same time the focus of a pencil of incident rays, then the focus of the incident pencil corresponding to the reflected one first mentioned, is also the focus of the reflected pencil corresponding to the incident one first mentioned. Thus the points A and A_2, in fig. 1, are reciprocal foci.

5. The linear dimensions of the image produced by a plane reflector are equal to those of the object, or image, in which the foci of the incident pencils are situated, and it is erect with regard to that object or image.

Spherical Reflecting Surfaces.—1. Polished reflecting surfaces, consisting of small segments of spheres, have the property of reflecting rays of light belonging to a given incident pencil in such a manner, that they may be regarded, after reflection, as belonging to one reflected pencil, and either as parallel to one another, or as having a common focus. This is strictly true only when the focus of the incident pencil coincides with the centre of curvature of the reflecting surface, or is a point in that surface ; and, in such cases, the focus of the reflected pencil coincides with that of the incident one. In no other case do the direction-lines of the reflected rays intersect one another accurately in one point, or proceed parallel to one another ; but they may be regarded as doing so very nearly, except when the reflecting surface constitutes a pretty large segment of a sphere, or when the direction of the incident pencil is very much inclined to the axis of the reflecting surface.

2. A pencil incident on a spherical reflecting surface has a common axis with the reflected pencil corresponding to it ; that is to say, the focus of the reflected pencil is situated in a straight line drawn through the focus of the incident pencil, and through the centre of curvature of the reflecting surface. A line so drawn will intersect the reflecting surface, or a continuation of it, at right

angles; and if the line of direction of one of the incident rays were to coincide with the axis of the pencil, it would be reflected in the line of its original direction; so that if all the reflected rays are either parallel to one another, or possessed of a common focus, they must be either parallel to, or have their focus in the axis in which the direction line of one of them lies. When the reflected rays have *not* all a common focus in the strict sense of the term, we must regard a mean point as their focus. When the incident pencil is a principal one, this mean point will always be in the axis; in most other cases, it will be very nearly so: but it must be observed that, in the case of some very oblique pencils, it may happen that no two of the reflected rays will intersect one another exactly in the axis of the incident pencil; and due allowance must be made for this circumstance in the practical application of the statements which follow.

3. The focus of a pencil incident on a spherical reflecting surface and that of the corresponding reflected one are reciprocal, and are termed *conjugate* foci; but they are not equidistant from the centre or *apex* of the reflecting surface, unless they are either in the surface itself, or situated at distances from the apex equal to the length of the radius of curvature of the surface; and they are not necessarily on opposite sides of the reflector.

4. The focus of the reflected pencil corresponding to a *principal* incident pencil composed of parallel rays, is a point in the axis of the reflector, midway between the centre of curvature and the apex. The distance between the apex and the principal focus is termed the principal focal distance, or the focal distance of the reflector.

5. The linear dimensions of the image formed by the foci of reflected pencils, and those of the object or image in which the foci of the corresponding incident pencils are situated, are directly proportioned to their respective distances from the apex, or from the centre of curvature of the reflecting surface. When the foci of the reflected pencils are on the same side of the reflecting surface with those of the incident ones, the image formed by the foci of reflected pencils is *inverted* with respect to the object or image in which the foci of the corresponding incident pencils are situated. If the foci of the reflected pencils are on the side of the reflector opposite to that on which the foci of the incident pencils are situated, the image formed by the former will be *erect* with regard to the object or image in which the latter are situated.

Concave Spherical Reflectors.—1. If the focus of a pencil of rays incident on a concave spherical surface is situated in front of the surface, and at a distance from the apex greater than the principal focal distance of the reflector, the rays of the corresponding reflected pencil will converge to a real focus in front of the reflector, and further from its apex than the principal focus is. Thus the rays A a, A a_3, incident on the surface R R′ in fig. 2, would converge after reflection to the point A_2 but for the interposition of the eye E.

2. If the focus of the incident pencil is in front of the reflecting surface, and at a distance from the apex equal to that of the principal focus, the reflected rays will follow lines of direction parallel to one another.

3. If the focus of the incident pencil is in front of the reflector, and nearer to the apex than the principal focus, the reflected rays will diverge, and have an imaginary focus behind the reflector.

4. If the rays composing the incident pencil converge towards an imaginary focus behind the reflector, the reflected rays will converge to a real focus in front of the reflector, and nearer to its apex than the principal focus is.

5. If the lines of direction of the rays which compose the incident pencil are parallel to one another, the rays of the corresponding reflected pencil converge to a real focus in front of the reflector, and at a distance from its apex equal to the principal focal distance.

Convex Spherical Reflectors.—1. If the focus of an incident pencil is situated in front of a convex spherical reflector, the reflected rays will diverge, and have an imaginary focus situated behind the reflector at a distance from the apex less than the principal focal distance.

2. If the rays of which the incident pencil is composed converge towards an imaginary focus situated behind the reflector, and at a distance from the apex less than the principal focal distance, the reflected rays will converge to a real focus in front of the reflector. Thus the rays a a and $a'a_3$, which are converging towards A′ in fig. 3, would converge after reflection to the point A_2 if the eye E were not interposed.

3. If the rays of which the incident pencil is composed converge towards an imaginary focus situated behind the reflector, and at a distance from the apex equal to the principal focal distance, the lines of direction of the reflected rays will be parallel to one another.

4. If the rays of which the incident pencil is composed converge towards an imaginary focus situated behind the reflector, and at a distance from the apex greater than the principal focal distance, the reflected rays will diverge, and have an imaginary focus behind the reflector, and further from its apex than the principal focus is.

5. If the lines of direction of the rays composing an incident pencil are parallel to one another, the reflected rays will diverge and have an imaginary focus behind the reflector, and at a distance from its apex equal to that of the principal focus.

From what has been stated above, it will be observed that the effect of regular reflection from a concave surface is to render the rays of a reflected pencil less divergent than those of the corresponding incident one, or parallel to one another, or convergent when the incident pencil consists of divergent rays, to render them convergent when the incident pencil consists of parallel rays, and to render them more convergent than those of the incident pencil when the latter are convergent.

The effect of regular reflection from a convex surface is to render the rays of a reflected pencil more divergent than those of the corresponding incident one, when the latter consists of divergent rays; to render them divergent when the incident pencil consists of parallel rays; and to render them divergent, or parallel, or less convergent than those of the incident pencil, when the latter are convergent. Thus, a concave reflector condenses, and a convex one disperses the light.

Refraction of Light.—Rays of light passing from any source through a single medium of uniform density, do so in straight lines; but if a transparent medium, differing in certain optical properties from that through which the rays have been passing, is placed in their course, all of them which do not fall perpendicularly on the surface of the new medium, and which are transmitted through it, have their lines of direction altered, or are refracted at the surface of it.

The angle of refraction—that is, the angle which the direction line of a ray so deflected makes with a straight line drawn through the surface and at right angles to it at the point of incidence—bears such a relation to the angle of incidence that, for the same media, the sines of the angles of incidence and refraction are always similarly proportioned to one another. Thus, if we represent the sine of the angle of incidence of a ray passing from air into glass by the number 3, and the sine of the angle of refraction of the same ray by 2, and the sine of the angle of incidence of another ray passing from air into glass by 6, the sine of the angle of refraction of the second ray will be represented by 4.

When the ray is refracted in passing from the medium which has the less refracting power into that which has the greater, it is deflected towards the perpendicular, so that the angle of refraction is less than the angle of incidence. When it is refracted in passing from the medium which has the greater refracting power into that which has the less, it is deflected away from the perpendicular, so that the angle of refraction is greater than the angle of incidence.

The angle of *deviation*, or that which the direction line of the incident ray makes with that of the corresponding refracted one, is equal to the difference between the angles of incidence and refraction, and it is greater the greater they are.

Refraction at Plane Surfaces.—Refraction at a single plane surface tends to render the rays of a pencil refracted on entering a medium of higher refracting power than that through which it has been passing less divergent than those of the incident one, if the latter consists of divergent rays, and less convergent than those of the incident one, if the rays composing it are convergent.

If a ray of light passes through a plate of glass or other transparent substance, the refracting power of which is greater than that of air, and the surfaces of which are plane and parallel to one another, it either passes on unrefracted, or it is deflected at each surface of the second medium, so that the angle of deviation at the second refraction is equal to the angle of deviation at the first; and, as these angles are on opposite sides of the direction line followed by the ray while passing through the second medium, the direction line of the ray, after it has been twice refracted, will be parallel to the line of direction which it followed before the first refraction.

The refracted pencil will have its diameter somewhat diminished as compared with what it would have been had there been no refraction of any of its rays, if the incident pencil consists of divergent rays; and somewhat increased, if the incident pencil consists of convergent rays; but the axis of the refracted pencil will be parallel to that of the incident one, and it will be nearly in the same straight line with it if the refracting body is very thin; while the divergence or convergence of the rays composing the refracted pencil will be the same as the divergence or convergence of those composing fhe incident one.

If the two surfaces of the second medium are inclined to one another at an angle, as in the case of a prism, a ray incident on one of them will, if transmitted at all, pursue a course after the second refraction not parallel to its original direction; but it will be deflected away from the angle formed by the intersection of the two surfaces, after it has passed through the refracting body.

Spherical Refracting Surfaces.—Rays of light belonging to a pencil incident on a refracting surface which constitutes a segment of a sphere, will either have a common focus, or proceed parallel to one another after refraction.

If the focus of the incident pencil is a point in the refracting surface, or coincides with its centre of curvature, the focus of the refracted pencil will be in the same point.

In all other cases, the rays composing the refracted pencil have only an approximation to a common focus, which is more nearly accurate the smaller the segment of the sphere constituting the refracting surface is, and the less the direction of the incident pencil is inclined to the axis of the surface; or else they are only approximately parallel to one another.

A pencil composed of rays refracted at a spherical surface has a common optical axis with the incident pencil corresponding to it; and this axis lies in a straight line drawn through the focus of the incident pencil and the centre of curvature of the refracting surface.

A spherical refracting surface has two principal foci—the one the focus of the refracted pencil corresponding to a principal pencil consisting of parallel rays passing from the medium which has the less refracting power into that which has the greater; the other the focus of the refracted pencil corresponding to a principal pencil composed of parallel rays passing from the medium which has the greater refracting power into that which has the less. The distance of the one principal focus from the centre or apex of the refracting surface is equal to the distance of the other from the centre of curvature of the surface. These distances depend on the length of the radius of curvature of the surface, and on the relative refracting powers of the media.

If the surface of the medium which has the higher refracting power presents a convexity towards the medium which has the lower, and if the rays composing the incident pencil have their focus between the refracting surface and its centre of curvature, the rays of the refracted pencil will converge less than those of the incident pencil, when the light is entering the medium of higher refracting power; and they will diverge more than those of the incident pencil when the light is entering the medium of lower refracting power. If the surface of the medium which has the higher refracting power presents a concavity to that which has the lower, and if the rays composing the incident pencil have their focus between the refracting surface and its centre of curvature, the rays of the refracted pencil will diverge less than those of the incident pencil when the light is entering the medium of higher refracting power, and they will converge more than those of the incident pencil when the light is entering the medium of lower refracting power.

In all other cases, a refracting surface, whose *convexity* is presented to the medium of less refracting power, *condenses* the light refracted at it; and one whose *concavity* is presented to the medium of less refracting power *disperses* the light refracted at it.

Double Convex Lenses.—A double convex lens is composed of a transparent body having two spherical refracting surfaces, the convexities of which are turned towards a medium or media of less refracting power, and which have a common axis.

Rays which originally belonged to one incident pencil may be regarded as belonging to one pencil after they have been refracted at the two surfaces of the lens, when these surfaces constitute small segments of spherical surfaces, and when the obliquity of the incident pencil is not very great.

There is a point in the axis of every lens through which, if we draw a straight line in any direction, it will make equal angles with the two surfaces at the points where it cuts them. A ray which passes through this point in the axis will be refracted, so that its line of direction, after the second refraction, will be parallel to its line of direction before the first, as if it had passed through two plane refracting surfaces parallel to one another; and if the thickness of the lens is disregarded, as it may generally be, the ray may be regarded as passing through unrefracted. The foci of the incident and refracted pencil to which such a ray belongs will both be situated in its line of direction. The point in the axis of the lens above referred to is termed the optical *centre* of the lens, and a straight line drawn through it, and through the focus of an incident pencil, is regarded as the optical axis of that pencil, and of the corresponding refracted one. When the surfaces of a double convex lens have equal radii of curvature, the optical centre is equidistant from them.

The principal foci of a double-convex lens are equidistant from the optical centre, and in the case of glass lenses having surfaces of equal curvature, the principal focal distance, measured from the centre, is equal to the radius of curvature of one of the surfaces.

1. When the focus of a divergent pencil, incident on a double-convex lens, is at a distance from the optical centre greater than the principal focus of the lens, the rays of the corresponding refracted pencil converge to a real focus on the other side of the lens. Thus, the rays coming from the point A, in fig. 3, would converge to the point A′, in the axis A c′ A′, if the reflector R R′, were not interposed.

2. If the focus of a divergent incident pencil is at a distance from the optical centre equal to that of the principal focus, the corresponding refracted pencil will consist of parallel rays.

3. If the rays composing the incident pencil diverge from a focus nearer the optical centre than the principal focus is, the rays of the refracted pencil will diverge, and have an imaginary focus on the same side of the lens as the focus of the incident pencil is, but further from it.

4. If the rays of the incident pencil converge towards a focus on the other side of the lens, the rays of the refracted one will converge to a real focus between the lens and the focus of the incident pencil.

Double Concave Lenses.—When the denser of the transparent media through which light is supposed to be passing presents two concave surfaces to the rarer, the effect produced on the light which has passed through it will be to disperse it instead of condensing it, as would be done by a double convex lens.

The statements made with regard to double convex lenses may, however, be applied to double concave ones, if we simply reverse such of them as refer to the positions of the foci of refracted pencils, and bear in mind that the rays of which a pencil refracted by a double concave lens consists, are always divergent, and have an imaginary focus on the same side of the lens with that of the incident pencil, if the latter is divergent, and on the opposite side, if it is convergent; except when the incident rays converge towards a focus nearer the lens than its principal focus, in which case the refracted rays will converge to a real focus on the same side of the lens with that of the incident pencil; and when the incident rays converge to a focus at a distance from the optical centre equal to the distance of the principal focus, in which case the refracted rays will be parallel to one another.

The images formed by the foci of pencils refracted at lenses or single spherical refracting surfaces are *erect*, with respect to the object or image in which the foci of the incident pencils are situated, when the foci of the incident and refracted pencils are on the same side of the lens or surface, and *inverted* when they are on opposite sides; and their linear dimensions are to those of the object or image in which the foci of the incident pencils are situated, as their respective distances from the optical centre are to one another.

Total Reflection.—When a ray is incident on the second surface of a transparent medium at such an angle that the corresponding angle of refraction would be greater than 90°, the ray cannot be transmitted, but it is reflected according to the laws of regular reflection, and it passes out through one of the surfaces of the transparent body after being so reflected once or oftener. Prisms whose surfaces are inclined to one another at a sufficiently great angle have the property of reflecting all the light transmitted through any of their faces in this manner; and they are sometimes used as ophthalmoscopic reflectors, with a hole bored through them, in order that the light returning from the patient's eye may not be reflected away before it reaches the eye of the observer.

The human eye contains a number of refracting surfaces, the axes of which coincide exactly, or very nearly, with one another. The effects produced by this combination resemble those produced by a double convex lens, or a single spherical refracting surface having its convexity towards the medium of less refracting power. Like them, too, it has an optical centre, any ray passing through which is either unrefracted, or refracted parallel to its original direction.

The position of the optical centre varies according to the focal adjustment of the eye, being further from the retina when the eye is adjusted for near objects than it is under other circumstances, and its mean position has long been a point in dispute; but there seems to be very little doubt that it may be regarded as very nearly in the centre of curvature of the cornea.

The eyes in the accompanying diagrams are represented as homogeneous bodies, possessed of a single condensing refracting surface, which is regarded as the optical equivalent of the various surfaces in a real eye. By giving such hypothetical eyes a higher index of refraction than that of any of the media of a real eye, we may preserve the proportion between the distances of the cornea and retina from the optical centre almost unchanged, while substituting an equivalent for a real eye, which may be assumed to be quite accurate, in so far as concerns any optical conclusions with which we have to do.*

N.B.—The following formulæ for determining approximately the position of the focus of a pencil of reflected or refracted rays, when that of the focus of the corresponding incident pencil is known, have been employed in the construction of the diagrams illustrating this article.

They are all identical with, or deducible from, those to be found in optical text-books; indeed, the first of them might, with certain modifications, be used in every case; but it will be found more convenient and less likely to give rise to accidental errors in the application of them, to have them presented in the form which leads most directly to the desired result in each particular case.

The distances of the foci are measured from the apex in the case of reflectors, from the optical centre in the case of lenses, and from the centre of curvature (which is also the optical centre), in the case of single spherical refracting surfaces, as this mode of measuring gives the greatest facilities for estimating the relative sizes of objects and images; and the most distant, rather than a mean point of intersection of the rays, is considered as the focus.

When the result has a negative sign prefixed to it, it will indicate that the refracted rays diverge from an imaginary focus.

I.—REFLECTORS AND LENSES.

Let F = The distance of the principal focus of a lens or reflector measured from the optical centre in the case of the lens, and from the apex in the case of the reflector.

" f = The distance of the focus of incident rays similarly measured.

" f' = The distance of the focus of reflected or refracted rays similarly measured.

1. Concave spherical reflector or double convex lens.

(1.) Incident rays divergent, $f' = \frac{f \times F}{f - F}$ ....(i.)

(2.) Incident rays convergent, $f' = \frac{f \times F}{f + F}$ ....(ii.)

Convex spherical reflector or double concave lens.

(1.) Incident rays divergent, $f' - \frac{f \times F}{f + F}$ ....(iii.)

(2.) Incident rays convergent, $f' = \frac{f \times F}{F - f}$ ....(iv.)

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* The same mode of representation has been adopted by Stellwag von Carion —Theorie der Augenspiegel: Vienna, 1854.

II.—SINGLE-CONDENSING SPHERICAL REFRACTING SURFACE.

In this case the substance of the higher refracting power presents a convex surface to that of the lower. The optical centre is in the body of higher refracting power, and so is the principal focus for rays refracted on entering that body, while that for rays emerging from it is in the medium of lower refracting power. If we term the latter the anterior, and the former the posterior principal focus, we find that the distance of the anterior from the optical centre is equal to the sum of that of the posterior and the length of the radius of curvature; and, by dividing the one distance by the other, we get approximately the indices of refraction for rays entering and emerging from the denser medium; so that, provided the radius of curvature and one of the principal focal distances are known, we have the necessary elements for calculating the foci both of rays entering and of rays emerging.

Let F = Distance of posterior principal focus from optical centre.
" r = The radius of curvature of the surface.
" $F + r$ = Distance of anterior principal focus from optical centre.
" f = Distance of focus of incident rays similarly measured.
" f' = Distance of focus of refracted rays similarly measured.

1. Light entering medium of higher refracting power.

(1.) Incident rays divergent, $f' = \frac{f \times F}{-(F + r)}$ ....(v.)

(2.) Incident rays converging to a focus beyond the optical centre—

$$f' = \frac{f \times F}{f + F + r} \qquad \text{(vi.)}$$

(3.) Incident rays converging towards a focus between the surface and optical centre—

$$f' = \frac{f \times F}{(F + r) - f} \qquad \text{(vii.)}$$

2. Light emerging from medium of higher refracting power.

(1.) Incident rays diverging from a point beyond the optical centre—

$$f' = \frac{f\,(F + r)}{f - F} \qquad \text{(viii.)}$$

(2.) Incident rays diverging from a focus between the surface and optical centre—

$$= -\frac{f\,(F + r)}{f + F} \qquad \text{(ix.)}$$

(3.) Incident rays convergent, $f' = \frac{f\,(F + r)}{f + F}$ ....(x.)

Part II.—MODES OF ILLUMINATING THE FUNDUS OCULI.

There are two circumstances which it might seem almost superfluous to allude to here, were it not that the neglect of them is calculated to vitiate the conclusions which may be drawn with respect to the extent of the area illuminated under given conditions, and to the intensity of the illumination; while, at the same time, one or other of them is occasionally overlooked by ophthalmoscopists, if not, to some extent at least, by accomplished writers on this subject. The first of these, and the most obvious, is the effect which the refracting surfaces of the eye have in modifying the distribution of the light which has passed through them; so that it would be wrong, for example, to conclude that what we see when we direct the light reflected from a concave reflector on a wall or a screen, holds good with regard to the illumination of an eye placed at the same distance. The second is, that what may be true of the illumination produced by a single radiant point in a source of light is not necessarily true of that produced by the whole source, however small it may be, short of being infinitesimal.

The illuminating apparatus of an ophthalmoscope may consist of a simple reflector, or of a combination of a reflector with a lens or lenses, or with a refracting surface or surfaces. There are two modes of examining the fundus oculi which are most frequently pursued, one of which renders it desirable that the observer, and consequently the reflector, should be as near to the eye observed as possible, while the other requires that the distance should be from 10 to 18 inches.

I propose, in the first place, to give a comparative view of the effects produced by what may be regarded as types of the various instruments commonly employed; secondly, to make a statement of the general principles affecting the extent of the area illuminated, and the intensity and uniformity of its illumination; and lastly, to make a few practical remarks with regard to the special advantages which particular forms of ophthalmoscope possess, and with regard to the manner of using them.

1. *Plane Reflector held close to Eye under Examination.*—Let A B (fig. 1) represent the flame of a lamp or candle; let R R′ represent a plane reflecting surface, placed at a distance of 4 inches from the flame; let E represent an eye which is adjusted for the distance of 5 inches, and whose optical centre is 1 inch from the centre of the reflector.

On the principles laid down in part first, pencils of light coming from the points A and B, and incident on the reflecting surface, will have their foci altered after reflection to the points A_2 and B_2, situated in the axes A A_2 and B B_2, and at distances from the centre of the reflecting surface equal to those of the points A and B; and an erect image of the flame will be formed at $A_2 B_2$. The rays of the reflected pencils which have their foci at A_2 and B_2 are refracted at the eye E, and brought to real foci at the points A_3 and B_3, which are conjugate foci with A_2 and B_2 respectively, so as to form an inverted image of the flame, the length of which is to that of the image A_2B_2, or the flame A B, as A_3 C is to C A_2, or about

1-5th in the diagram.* The extent of the area thus illuminated will, accordingly, be 1-25th of that of the flame A B.

2. *Concave Reflector held close to Eye under Examination.*— Let A B (fig. 2) represent the flame as before; R R′ a concave reflecting surface of 2 inches focal distance, with its apex at a distance of 4 inches from the flame, and distant 1 inch from C, the optical centre of the eye E, which is the same in its dimensions as the eye in fig. 1, and supposed to be similarly adjusted.

The rays composing the pencils Aa, Aa_3, and Bb, Bb_3, and incident on the reflector, would, but for the interposition of the eye E, come to real foci at the points A_2 and B_2 in the axes A*c* A_2 and B*c* B_2, drawn through *c*,† the centre of curvature of the reflector, and at distances from the apex equal to the distances of A and B from the same point (formula i.). Thus we have at $A_2 B_2$ an inverted image of the flame, equal in size to it; and this image would be real but for the interposition of the eye E. The rays belonging to pencils converging towards A_2 and B_2, and incident on the eye E, will be brought to real foci in the axes $a_2 C A_2$ and $b_2 C B_2$, at distances from C which may be found by formula vi., and will form a real image at $A_3 B_3$, erect with regard to the image $A_2 B_2$, and inverted with regard to the flame. After crossing one another at A_3 and B_3, the rays of each pencil will again diverge, and go to form circles of dispersion round the axes upon the retina, which is supposed to be behind the posterior principal focus of the refracting surface, and of course behind $A_3 B_3$, which is in front of it. If the rays were brought to foci on the retina, the linear dimensions of the illuminated area would, in this case, be to those of the flame as 1 to 3, and the area as 1 to 9; but it is somewhat increased by the circles of dispersion.

3. Combination of *convex* reflector with double convex lens— reflector held close to eye under examination.

Let AB (fig. 3) represent the flame, LL′ a double convex lens, supposed to be about 1¼ inch focal distance, and placed about 2½ inches from the centre of the flame, RR′ a convex reflector, placed

* The proportion between the size of the eye and the distances, &c., represented in these diagrams, is of course different from what it would really be in almost any actual case; but this does not affect the application of the principles illustrated by them to real cases.

† It has been necessary to shift the position of the point *c* in this diagram, from *c′*, which is the real centre; because, owing to the obliquity with which the light falls upon the reflector, none of the rays represented in the diagram will really cross each other in lines drawn from A and B, through *c′*. But the rays which originally came from A and B, and which are represented in the diagram, will cross very nearly in the points A_2 and B_2 respectively. It must be observed that this and other slight inaccuracies in the drawing of the diagrams 2, 3, and 4, are attributable to the obliquity with which the light is made to fall on the reflectors, while the distances are calculated as if the pencils incident on the reflector were principal ones, and the foci are represented as if there were no spherical aberration, and the images as if there were no distortion. These circumstances however, do not much affect the general truth of our conclusions.

with its apex at a distance of 4 inches from the flame, and 1 inch from the optical centre of the eye E, which is adjusted as formerly, and let the focal distance of the reflector be $1\frac{1}{3}$ inch.

Rays coming from A and B, and incident on the lens LL′, would, but for the interposition of the reflector, be brought to real foci at A′ and B′, in the axes Ac′ A′ and Bc′ B′, at distances from c′, the centre of the lens, which may be found by formula i.; and an inverted image of the flame would be formed at A′ B′, the centre of which would be at a distance from c′ equal to that of the centre of the flame A B; so that the image would be nearly equal in size to the flame, while its centre would be at a distance of about 1 inch from the apex of the reflecting surface.

The foci of rays proceeding towards A′ and B′, and incident on the surface RR′, will, after reflection, be changed from A′ and B′ to A_2 and B_2, points in the axes cA′ A_2 and cB′ B_2, drawn from c, the centre of curvature of the reflector, through A′ and B′, and their distances may be calculated by formula iv.

Thus, but for the interposition of the eye E, we should have an image at $A_2 B_2$, erect with regard to the image A′ B′, but inverted with regard to the flame AB, and its centre would be in this case about 4 inches from the apex of the reflector, while its linear dimensions would be to those of the image A′ B′, or the flame AB, as 4 is to 1.

Rays having their foci at A_2 and B_2, and incident on the eye E, will, after refraction, be brought to real foci at A_3 and B_3, in the axes, a_2 CA_3 and b_2 cB_3, at distances from C which may be found by the formula vi.; and from these points they will diverge and form circles of dispersion round the axes upon the retina. If A_3 and B_3 were upon the retina, the linear dimensions of the area illuminated would be to those of the image $A_2 B_2$ as 1 is to 3, and to those of the flame AB as 1 is to $\frac{3}{4}$; but they will be somewhat larger, in consequence of the circles of dispersion.

4. Combination of *concave* reflector with double *convex* lens—reflector held at some distance from eye under examination, and lens a little in front of eye.

Let E (fig. 4) be the eye under examination; let AB be the flame of a lamp; let RR′ be a concave reflector, of 2 inches focal distance, held with its apex at a distance of 6 inches from the flame, and $5\frac{1}{12}$ inches from C, the optical centre of the eye E, adjusted as formerly; and let LL′ be a double convex lens, of $\frac{2}{3}$ of an inch focal distance, held so that its centre c′ is $4\frac{1}{3}$ inches from the apex of the reflector, and about $1\frac{1}{12}$ inch from C.

Rays coming from A and B, and incident on the reflector, will be brought to real foci at A_2 and B_2, in the axes Ac A_2, Bc B_2, drawn from A and B through c, the centre of curvature of the reflector, and will form a real inverted image A_2 B_2, at a distance of 3 inches from the reflector (form. i.), and half the size of AB.

Rays coming from A_2 and B_2, which are at a distance of $1\frac{1}{3}$

inch from c', would, after refraction, be brought to real foci at A′ and B′, in the axes, $A_2\,cA'$ and $B_2\,cB'$, but for the interposition of the eye E. The distances of A′ and B′ from c will be $1\frac{1}{3}$ inch (form. i.), and the linear dimensions of the image A′ B′ will be equal to those of the image $A_2\,B_2$, or half those of the flame AB.

Rays which have their foci at A′ and B′, and enter the eye E, will, after refraction, be brought to foci at A_3 and B_3, in the axes, A′C and B′C, and at distances from C which may be found by form. vi. An image will be formed at $A_3\,B_3$, erect with respect to the image A′B′, and to the flame, but inverted with respect to the image $A_2\,B_2$; and the rays will diverge from points in it, forming very large circles of dispersion, overlapping one another on the retina. The linear dimensions of the illuminated area on the retina will, in this case, be to those of the image A′B′ as 4 to 1, or to those of the flame as 2 to 1, with a certain addition, due to those parts of the circles of dispersion which lie to the outer side of the lines drawn from C through A′ and B′, and which are comparatively small in the present case.

Extent of Area Illuminated.—It will be seen on inspecting the diagrams, that there are two circumstances which mainly determine the extent of the area of the fundus oculi which is illuminated, viz.:—first, the magnitude of the angle which is subtended at the optical centre of the eye by the image of the luminous source in which the foci of rays incident on the eye are situated; that is to say, the angle A_2CB_2, in figs. 1, 2, and 3, or the angle A′CB′ in fig. 4; and secondly, the size of the circles of dispersion, if there are any formed upon the fundus oculi. It does not follow, however, that the increase in the illuminated area produced by the presence of circles of dispersion is exactly proportioned to the area of each of these circles, or even to the relation which one of them bears to the whole illuminated area, because they may overlap one another to a great extent, as in fig. 4; but it is only those portions of the circles of dispersion which lie outside the straight lines limiting the angle above mentioned that come to tell in increasing the area illuminated.

The greater the angle which the optical axis of a pencil, refracted at the eye, makes with the axis of the eye at the optical centre, the less accurately will the point where the axis of the pencil meets the fundus oculi be in the centre of the circle of dispersion formed by the rays of the pencil; indeed, there may be cases in which it lies outside the circle of dispersion altogether. The axes of the pencils, which are formed of rays which originally came from the extreme points of the source of light, are the lines which limit the angle alluded to above; and, if they are inclined to the axis of the eye, and if circles of dispersion are formed by rays which belong to these pencils, and which have been already brought to foci in the eye, the greater part of each will fall to the inner side of the point where the axis meets the fundus oculi;

whereas, if they are formed by rays whose foci are behind the eye, the greater part of each will fall to the outer side of the axis, so that the area illuminated will be larger in the latter case than in the former. Thus, if E (fig. 5) were adjusted so that rays coming from a flame AB, came to foci at A_2 and B_2, and formed an image there, the illuminated area on the retina would have the diameter a_2b; whereas, if it had its refracting power altered without altering its dimensions, so that the foci should be at A_3 and B_3, the illuminated area would have the diameter $a_2\beta$, although the circles of dispersion would be the same size in both cases.

If there is no lens interposed between the eye and the reflector (as in figs. 1, 2, and 3), the angle which is subtended at the optical centre of the eye by the reflector itself, or by that portion of it which is illuminated by light passing through the lens (in fig. 3) will be more or less exactly the limit of the angle which the illuminated area on the retina can subtend at the same point, according as the eye is more or less accurately adjusted for the distance at which the reflector is situated, however great the angle may be which is subtended at the optical centre C, by the image $A_2 B_2$. The reason of this is, that light reflected—regularly or not—from any point in the reflecting surface will, if the eye is adjusted for the distance of that point, strike the retina at a point in a straight line drawn from the point in the reflector through the optical centre of the eye, and such lines, drawn from opposite points in the circumference of the reflector, limit the angle which it subtends at C. In short, we may refer the light which is incident on the eye to one or other of two sets of pencils, one set having foci at points in the image of the flame, and the other set having foci at points in the reflecting surface, but both sets possessing the same individual rays in common. If the reflector alone is in focus, and if it subtends a greater angle than the image of the flame $A_2 B_2$, the illuminated area on the retina of the eye may be regarded either as a diffuse image of the flame, produced by circles of dispersion instead of foci, or as an image of that part of the reflector which sends light into the eye, produced by the foci of rays coming from points in the reflecting surface and refracted at the eye. If the reflector subtends a smaller angle than the image $A_2 B_2$, and if it alone is in focus for the eye, the illuminated area on the retina may be regarded either as an image of the reflector, formed by the foci of refracted pencils corresponding to pencils which diverged originally from points in the reflecting surface, or as a diffuse image of part of the flame formed by circles of dispersion overlapping one another. If both the reflector and the image $A_2 B_2$ are in focus—a very rare case —the image on the retina may be regarded as an accurate image of one, or of a part of the other; and if neither is in focus, the illuminated area may be regarded as a diffuse image of one, or of a part of the other, as the case may be.

Unless the flame is very large, it will rarely happen that the image of it produced by the reflector subtends so large an angle at the optical centre of the eye as the reflector itself does, or that light will enter the eye from every point of the reflector, unless the latter is withdrawn to a distance of several inches; in which case the shorter the focal distance of the reflector—if a concave one is used, and of the whole apparatus, if such a combination as that represented in fig. 3 is employed—the sooner will the result be attained.

In such a case as that represented in fig. 4, the limit of the angle which can be subtended at the optical centre of the eye by the illuminated area on its retina, will be the angle subtended at the same point by the magnified image of the reflector as seen through the lens by the eye; and this limit will be more or less accurate according to the focal adjustment of the eye.

The nearer the optical centre of the eye is to the centre of the reflecting surface, the more nearly will the angle subtended by the image A_2 B_2 at the optical centre of the eye correspond with the angle which A_2 B_2 subtends at the centre of the reflecting surface; and in the cases represented in figs. 1 and 2, this angle will always be equal to the angle which the flame subtends at the same point. In such a case as that represented in fig. 3, the angle which the image A' B' subtends at the apex of the reflector is equal to the angle which the image A_2 B_2 subtends at the same point.

We may, then, lay down the following principles regarding the extent of the area illuminated:—

1. Reflector as close as possible to the eye illuminated.

The larger the source of light is, and the nearer it is to the reflector in the cases represented in figs. 1 and 2, the larger will the illuminated area on the retina be, unless the distance between the optical centre of the eye and the apex of the reflector is considerable in proportion to the focal distance of the latter, because these are the circumstances which go to increase the angle subtended both at the reflector and at the eye by the image A_2 B_2; while in the case represented in fig. 3, the larger the source of light is, the larger, *ceteris paribus*, will be the image A' B', and the nearer A' B' is to the reflecting surface, the larger will be the angle which it subtends at the centre of the reflecting surface, and consequently the larger will be the angle which A_2 B_2 subtends at the same point, and at the optical centre of the eye.

In cases where the source of light is so large that its image subtends a larger angle at the optical centre of the eye than the reflector does even when held close to the eye, the larger the reflector is, the larger will be the area of the fundus oculi illuminated.

When the image A_2 B_2 subtends a very small angle at the optical centre of the eye, the increase in the illuminated area due to circles of dispersion of a given diameter will be both proportionally and absolutely greater than when the angle subtended by A_2 B_2 is large, if the circles are formed by rays already brought to real foci in the eye; and it will be proportionally greater, but not necessarily absolutely greater, if the circles are formed by rays whose foci are behind the eye.

If the image A_2 B_2 subtends the same angle at the optical centre in two cases, if circles of dispersion are formed in the one case by rays brought to foci in front of the retina, and in another case by rays which have their foci behind the fundus oculi, and if other things are equal, the area illuminated in the latter case will be greater than that illuminated in the former.

A principal pencil entering the eye contains more light, has a larger diameter in every direction but one, and will form a larger circle of dispersion on the retina (if there are any formed), than a secondary one which has its focus at the same distance from the optical centre; and this circumstance, too, tends to moderate the increase of the illuminated area due to circles of dispersion, if the angle subtended by A_2 B_2 at the optical centre of the eye is large.

If the reflector is a condensing apparatus of very short focus, such as a strongly concave mirror, or a combination such as that in fig. 3, adjusted so that the image A_2 B_2 is comparatively near the reflector, and if the eye is not quite close to the reflector, the image A_2 B_2 may come to subtend a considerably larger angle at the optical centre of the eye than at the centre of the reflecting surface; but in cases where the distance between the eye and the reflector is so small, as compared with that between A_2 B_2 and either of them, that it may be disregarded, very little advantage will be gained by shortening the focus of the illuminating apparatus in so far as increasing the illuminated area is concerned, except what may be due to an increase in the size of the circles of dispersion; because the angle subtended by A_2 B_2 at the optical centre of the eye is nearly the same as that which it subtends at the centre of the reflecting surface, while the angle which it subtends there is equal to the angle subtended by the flame at the same point—and that is independent of the focal distance of the reflector.

The focal adjustment of the eye itself has, of course, an effect in modifying the extent of the area illuminated, and this is involved in the remarks which have already been made. An inspection of the diagrams will show that if the image A_3 B_3 is smaller than the pupil, the illuminated area will be increased in diameter the further the retina is in front of A_3 B_3, and also the further it is behind it; if, on the other hand, A_3 B_3 is larger than the pupil, the illuminated area will be larger the further the retina is behind A_3 B_3, and smaller the further the retina is in front of it, other things being equal.

If the state of focal adjustment of two eyes were to differ without a difference in their dimensions, but from a difference in refracting power, caused by differences in the state of the media, or by differences in the curvature or relative positions of some of the refracting surfaces, or, finally, by the absence of the crystalline lens from one of the eyes, the area illuminated would be larger, *ceteris paribus*, in the more presbyopic eye if the rays composing the incident pencils were too divergent to be brought accurately to foci on the fundus oculi of either eye,* and in the more myopic if the rays were too convergent.

2. Reflector held at a distance from eye illuminated—double convex lens between eye and reflector, as in fig. 4.

The principles which have been stated already may be applied to this case also, except that the image A′ B′ (fig. 4) takes the place of the image A_2 B_2 in figs. 1, 2 and 3, and that the angle which the lens subtends at the optical centre of the eye E, will be more or less accurately the limit of that which the illuminated area can subtend at the same point, according to the focal adjustment of the eye, and the relative distances of the reflector, the eye, and the lens. There is the less need for entering into details, because it is seldom difficult to illuminate a sufficiently large area of the fundus oculi in this way, if the humours of the eye are transparent.

The main point is to throw the image A′ B′ as near the optical centre of the eye as possible;† and we may find how to do so by observing the manner in which the light falls on the face of the patient before we direct it into the eye.

In any case in which circles of dispersion affect the size of the illuminated area, it must be remembered that the larger the pupil of the eye is, the larger will be the circles of dispersion.

Intensity of Illumination.—The intensity of the illumination will depend, in the first place, upon the intensity of the light which emanates from the source, and upon the proportion of it which is lost by transmission or absorption at the reflecting surface, or by reflection at the surfaces of the media through which it passes, and absorption in its passage through media of imperfect transparency. The size of the pupil, too, as determining the diameter of each pencil which enters the eye, is another important consideration.

Supposing all these considerations disposed of, it must be observed that the larger the area over which a certain amount of light is distributed, the less will be the intensity with which any

* If the presbyopia were to depend on absence of the lens, or on anything affecting the curvature or relative position of the refracting surfaces, there would probably be a slight difference in the positions of the optical centres of the eyes, which would diminish the difference in the sizes of the illuminated areæ in this case.

† On this point see Giraud Teulon, "Théorie de l'Ophthalmoscope," reprinted from the *Gazette Médicale*, p. 35. Paris, 1859.

one point in that area is illuminated. From this it results that if we increase the area illuminated, we must also increase the amount of light thrown into the eye, in order that the intensity of the illumination may be the same.

Now it so happens that so long as the pencils which enter the eye are large enough to fill the pupil, the quantity of light contained in each pencil will be, *ceteris paribus*, exactly proportioned to the square of the angle which the image, formed by the foci of the incident pencils ($A_2 B_2$, figs. 1, 2, and 3), subtends at the optical centre of the eye, in all cases in which the distances between optical centre, pupil, and cornea are so small relatively to their distances from the image $A_2 B_2$, that they may be disregarded; and the extent of the illuminated area, except in so far as it depends on circles of dispersion, is similarly proportioned to the square of the same angle.

This holds good whatever may be the distances between the flame, the reflector, and the eye, and whatever may be the focal distance of the illuminating apparatus, provided we suppose other things to be equal. To give a mathematical demonstration of it for every sort of case, would far exceed the limits of the present article; but we may take a couple of illustrations from diagrams, 1, 2, and 3.

In figures 1 and 2, where the distance of AB from the reflector is the same, the square of the angle aAa_3, formed by the extreme rays of a pencil which ultimately passes through the pupil, may be taken as the measure of the light contained in that pencil.

The angles aAa_3 and aA_2a_3 are equal to one another in each figure; and if we suppose the pupil to be in the same plane with the optical centre C, the angle aA_2a_3 or aA_2a' will be inversely proportioned to the distance A_2C, and so will the angle A_2CB_2; therefore the angle aAa_3 and the angle A_2CB_2 are both inversely proportioned to the distance A_2C, and their squares are inversely proportioned to the square of that distance. If there were no circles of dispersion, the extent of the illuminated area on the fundus oculi would be proportioned to the square of the angle A_2CB_2; and the intensity of the illumination produced would be the same at least for parts of the fundus near the posterior pole of the eye, because it depends on the amount of light contained in each pencil, which has already been shown to be regulated in the same way as the extent of the illuminated area by the distance A_2C.

If, again, we compare fig. 2 with fig. 3, it will be observed that A_2B_2 is four times as long in fig. 3 as it is in fig. 2; and, consequently, as the distance A_2C is the same in each case, the illuminated area will be 16 times as great in fig. 3 as it is in fig. 2. The diameter of a principal pencil, which enters the eye E, measured where that pencil leaves the reflecting surface, will be the same in each case, because the rays leave the reflectors at the same angles of convergence; but the pencil in fig. 3 will contain the light which has come from an area of the lens, the diameter of which is to that of the pencil at the reflector as $2\frac{1}{2}$ is to 1, while the relative distances of the lens in fig. 3, and the reflector in fig. 2, from the flame AB, are as $2\frac{1}{2}$ to 4. The quantity of light which falls on an area of the lens in fig. 3, having a diameter equal to that of the pencil, where it leaves the reflector in fig. 2 or 3, will be proportioned to that contained in the pencil in fig. 2, inversely as the square of the distances of the lens in fig. 3, and the reflector in fig. 2 from the flame; and the whole area of the lens, from which light comes to form the pencil in fig. 3, will be to the area last mentioned as the squares of their respective diameters, or as the square of $2\frac{1}{2}$ to the square of 1. By multiplying the squares of the numbers, $2\frac{1}{2}$ and 4, and the squares of 1 and $2\frac{1}{2}$ into one another, and dividing the product of the former by that of the latter pair, we get the relation between the quantities of light contained in the pencils in figs. 2 and 3 respectively; and it will be found that the pencil in fig. 2 contains 16 times as much light as that in fig. 3.

When there are circles of dispersion formed on the fundus oculi, the dispersion of the light caused by them will affect the intensity of the illumination of the central parts of the illuminated area very slightly, unless the portions of these circles which lie outside the axes of the extreme pencils going to form them, are very large relatively to the whole area illuminated; and this is due to the overlapping of the circles towards the centre, and the comparative faintness of the illumination at the circumferential parts of the illuminated area.

Uniformity of Illumination.—We may have a certain part of the illuminated area on the fundus oculi very brightly illuminated, and other parts very faintly so, and this has certain inconveniences connected with it.

If the light coming from all parts of the source were of uniform intensity, and if the reflecting surface were of uniform reflecting power at all its parts, we should attain the maximum amount of uniformity in the cases where the illuminated area of the fundus oculi presents an accurate image either of the flame or of the reflector. But when the flame has a dark space in its centre; and when the reflector has a hole in it, as is most generally the case in practice, there would be a dark space right in the centre of the illuminated area in either of the cases above referred to.

Besides this, a sharply defined image of the flame or reflector is rather apt to distract the attention of the observer, and to give an unnatural appearance to the objects illuminated by it. It is therefore desirable to have matters so arranged, that the light may form circles of dispersion on the fundus oculi in such a way as to cover the dark space referred to; and the best mode of insuring this is to throw the light upon the eye, so that the incident rays cannot be brought to foci on the retina after refraction, whether we regard them as belonging to pencils having their foci at the reflecting surface, or at the image A_2B_2 (figs. 1, 2, and 3), or A′B′ (fig. 4).

When a concave reflector is held close to the eye, and at a distance from the flame greater than its own focal distance, these objects will almost always be attained in greater or less perfection; and the same will hold good for any arrangement by which the image of the flame formed by the foci of pencils incident on the eye is behind it, and by which the eye cannot adjust itself for the reflector in consequence of its too great proximity, or of the interposition of a lens. Under such circumstances, the larger part of the circles of dispersion formed by rays which have crossed one another in the image A_3B_3 (figs. 1, 2, 3, and 4), will be thrown to that side of the axes of the pencils to which they belong, which is next to the centre of the illuminated area, and the central part will thus be illuminated with the least possible increase in the size of the whole illuminated area.

Practical Remarks.—It will be seen by inspecting the diagrams 1, 2, and 3, that when the reflector is held close to the eye, the area illuminated will be slightly larger, *ceteris paribus*, when we use a concave reflector than when we use a plane one; and that it may be greatly increased in size by such an apparatus as that represented in fig. 3, which is Zehender's ophthalmoscope. The ophthalmoscope of Coccius differs from that of Zehender, only in its having a plane instead of a concave reflector. Both of them present great advantages, as compared with concave reflectors, in the power which they give the observer of altering the size of the illuminated area, and of altering the distance of the foci of the reflected pencils by changing the position of the lens, without changing those of the flame and reflector; and, in this respect, Zehender's is the most perfect of the two. But it must be observed that in these instruments, the area on the surface of the reflector which is illuminated by light which has passed through the lens, limits the area of the fundus oculi which can be illuminated; that the former area will generally be smaller than the whole reflecting surface, unless the lens is very large; and that, as Zehender has himself remarked of his own ophthalmoscope,* as compared with that of Coccius, such forms of the instrument present peculiar advantages only when the distance between the reflector and the eye is small; in cases such as that represented in fig. 4, a concave reflector is to be preferred.

The ophthalmoscope of Helmholz presents, besides some other advantages to be considered afterwards, that of having no hole through the reflector. The illumination produced by it is comparatively faint, but still sufficient in general, and the pupil is all

* Græfe's Archiv für Ophthalmologie, Bd. I. Abt. I.

the less apt to contract inconveniently in those cases in which we do not wish to employ mydriatics if the light to which it is exposed is feeble. The instrument is inapplicable to the case represented in fig. 4. Various other forms of ophthalmoscope are employed, such as prisms and lenses silvered on the back;* but a concave reflector of 6 or 8 inches focus, and composed of speculum metal, or of a piece cut out of a glass globe silvered on the convex side, is perhaps the most convenient for general purposes. Metallic reflectors have certain advantages over the silvered glass ones; but the latter are cheaper, and less likely to lose their polish.

If we were to substitute a concave reflector of short focal distance for the one in fig. 2, there would be a slight increase in the amount of light thrown into the eye, and in the extent of the area illuminated; but the intensity would not be increased, at least at the central part, except under very unusual circumstances, most likely to occur in the examination of hyperpresbyopic eyes. The employment of reflectors of very short focal distance in such cases as that of fig. 4, is attended with obvious practical inconveniences.

The hole or space on the reflector left uncovered by silvering need not be more than about $\frac{1}{8}$ of an inch in diameter. Unless the flame is in the form of a short cylinder, it will be advisable to see that it is turned in such a direction that its image produced by the reflector has its greatest diameter at right angles to the axis of the eye observed; the area illuminated will then have the greatest diameter attainable under the circumstances.†

Some eyes, without really having any turbidity of the humours, are so difficult to illuminate, that one might readily suspect it; and this is particularly the case with regard to hyperpresbyopic ones, of which those deprived of the lens are extreme cases. Such eyes are the last in which one would expect, *a priori*, to meet with any difficulty of the sort; and, if the source of light and reflector were both very large, we should probably find none. The difficulty is usually met with when flame, reflector, and eye are very near one another, and the foci of the refracted pencils are far behind the retina. In this case, the circles of dispersion on the retina extend far beyond the points where the axes of the extreme pencils meet it, and the illumination is consequently faint, except in a very small space near the centre. It will often be found that by removing the flame a little further from the reflector when a concave one is used, the intensity of the illumination will be increased to the required degree. The pupils of such eyes, and indeed the eyes themselves, are generally small, if the defect is an original one.

* A full account of different instruments will be found in an able article by Dr. Liebreich of Berlin, prefixed to the second volume of Warlomont's French edition of Dr. Mackenzie's Treatise on the Eye, published at Paris in 1857.

† See figs. 1, 2, 3, and 4.

In conclusion, it may be remarked, that in the cases represented in figs. 1, 2, and 3, it is not necessary to illuminate so large an area as in that represented in fig. 4, because the area seen by the observer is smaller in the former ones.

Part III.—MODES OF VIEWING OBJECTS WITHIN THE EYE.

Having now considered the mode of illuminating the fundus oculi, we come to treat of the various conditions under which we may obtain a distinct view of objects situated upon it, by means of light reflected from their surfaces.

If we hold a biconvex lens between the eye and the page of a book, and at a distance from the book less than its own principal focal distance, we see an erect magnified virtual image of the print. If we remove the lens further from the book, the print appears more and more magnified; and when the distance between them has become equal to the principal focal distance of the lens, or nearly so, the letters begin to appear indistinct; while on withdrawing the lens a little further, the print becomes illegible. The reason of this is, that the rays which emanate from a given point on the page, are first rendered parallel to one another, and at length convergent, by their refraction at the surfaces of the lens. The majority of normal eyes can only be adjusted, so as to bring rays which are more or less divergent, or at most parallel to one another, to a focus on the retina; and consequently when the rays are convergent, they are brought to a focus in front of the retina, instead of upon it.

Supposing the lens to be held as above indicated, so that the rays coming from given points on the page are converging towards real foci behind the observer, he may diminish the indistinctness with which the object is seen by bringing his eye as close as possible to the lens; when the extreme rays of a given pencil which passes through his pupil will, when incident on his cornea, be inclined to one another at the smallest angle of convergence which is possible under the circumstances. On the other hand, the further he recedes from the lens, and the nearer his eye is to the inverted image of the book projected by the lens, the greater will that angle of convergence be, and the more indistinct will the print appear.

If the observer places close before his eye a biconcave lens having its negative focal distance shorter than the distance between it and the inverted image above referred to, the rays which have been rendered convergent by the biconvex lens will be again rendered divergent before they reach the eye, so that they may be brought accurately to foci on the retina; and the print may be distinctly seen, provided the focal distance of the concave lens is not so short as to render the rays too divergent.

If we hold the biconvex lens, as before, at a distance from the book equal to its own principal focal distance, and place another biconvex lens in front of the first, an inverted image of the print will be formed by the foci of rays rendered parallel by the first lens, and converging to real foci after having passed through the second. The distance of this inverted image from the second lens will be equal to the principal focal distance of that lens in the case supposed, and the observer must be at a distance from the image equal to that at which he ordinarily views small objects, in order to see its details distinctly. As the image is between the second lens and the observer's eye, his distance from that lens will then be the sum of its principal focal distance and the ordinary distance for distinct vision of near objects. If the observer should wish to see the details of the image on a large scale by approaching it, he may do so with the aid of a biconvex eye-piece to correct the too great divergence of the rays coming from foci in the image.

In regard to the magnifying power which may be obtained when an object is viewed through a lens placed so as to have it in its principal focus, it may be remarked that the magnitude of the virtual image seen by the observer is infinite, as is its distance from the lens, so that it cannot be directly compared with the magnitude of the object; but the angle which the image subtends at the centre of the lens is equal to the angle which the object subtends at the same point, and either of these angles is equal to the angle which the image subtends at the observer's eye, whatever the distance between the latter and the lens may be. Thus, if we suppose the lens to have one inch focal distance, the apparent magnitude of the image will be as great as that of the object when held at a distance of one inch from the eye; and, if we take ten inches as the ordinary distance for distinct vision of near objects, the apparent magnitude of the image seen by means of the lens will be ten times as great in linear dimensions, as that which the object would have if it were viewed under ordinary circumstances.

On this principle, the mode of estimating the magnifying power of a lens under the circumstances supposed, is to divide the distance at which one would naturally hold the object in order to view it directly, arbitrarily fixed at eight or ten inches, by the focal distance of the lens.

When, in addition to the first lens which has the object in its principal focus, a second lens is employed for the purpose of collecting the rays which come from the first lens to real foci, and the observer thus views a real image, it will suffice to find the relation between the magnitude of the real image and the object, because the observer will view the former from the same distance at which he would naturally look at the latter, if he were unaided by the lenses. The angle which the object subtends at the centre of the first lens, is equal to the angle which its virtual image formed by the imaginary foci of rays refracted at the lens subtends at the same point, and this virtual image subtends an equally great angle at the centre of the second lens, whatever the distance between the lenses may be; but the angle which the real image projected by the second lens subtends at the centre of that lens, is equal to the angle which the virtual image formed by the foci of rays refracted at the first lens and incident on the second subtends at the same point; therefore the real image subtends at the second lens an angle equal to that which the object subtends at the first.

When two objects, or an object and image, as in the present case, subtend similar angles at two points, their magnitudes will be to one another as their distances from the points respectively. In the case which we are now considering, the distance of the real image from the centre of the second lens is equal to the principal focal distance of that lens, while the distance between the object and the first lens is equal to the principal focal distance of the latter, and the linear dimensions of the real image will be to those of the object as the focal distance of the second lens is to that of the first. Hence, if the second lens has a shorter focal distance than the first, the image will be smaller than the object; and, if it has a longer, the image will be larger than the object.

If the object is nearer to or further from the first lens than its principal focus, the relative magnitudes of the object and image will depend upon the distance between the lenses, as well as on their respective focal distances; and the image formed by the foci of rays refracted at the second may be a real inverted image of an erect virtual one produced by the first lens, or a real erect image of a virtual inverted one produced by the first lens, or an erect virtual image of an inverted real one projected by the first lens, or finally, a real inverted image of another real inverted one produced by the first lens. In the former cases it will be inverted, and, in the last mentioned, it will be erect with respect to the object.

But, whatever the distance between the first lens and the object may be, if the distance between the two lenses is equal to the sum of their focal distances, the image produced by the second lens will be inverted with respect to the object; and its linear dimensions will be to those of the object, as the focal distance of the second lens is to that of the first.

When the object is nearer to the first lens than its principal focus, the image projected by the second lens will bear a larger proportion to the object than the focal distance of the second lens does to that of the first, if the distance between the lenses is less than the sum of their focal distances; and it will bear a less proportion, if the distance between the lenses exceeds the sum of their focal distances.

If the object is further from the first lens than its principal focal distance, the magnitude of the image projected by the second lens will be less in proportion to that of the object than the focal distance of the second lens is in proportion to that of the first, when the distance between the lenses is less than the sum of their focal distances; and greater in proportion when the distance between the lenses is greater than the sum of their focal distances.

If we now substitute an eye for the first lens, and provide for the illumination of objects situated on its retina, we may apply to ophthalmoscopic examinations what has been said with regard to the view of objects obtained, on looking through a biconvex lens, or a combination of such a lens with other lenses, provided we only make certain allowances for the fact that the anterior and posterior principal foci of a single spherical surface, such as that which is taken in the diagrams as the optical equivalent of the refracting powers in a real eye, are not equidistant from the centre; and we shall seldom have occasion to take even this circumstance into account.

There are two methods, accordingly, which may be pursued. By the one method the observer views objects situated within the eye under observation through the refracting media of that eye, which act as a magnifying glass, making use of a biconcave lens, if necessary, to correct the convergence of the rays. The image seen by him is then an erect one. When the other method is employed, the observer holds a biconvex lens before the eye under observation, and sees a real inverted image of the retina projected between him and the lens.

For the sake of brevity and distinction, the former method is sometimes termed the *direct*, and the latter, the *indirect* method.

1. *Direct method—Observation of erect virtual image.*—Let E, fig. 6, be the eye under examination; let C be its optical centre; and let A, B and D be points situated on its retina; let E_2 be the observer's eye; let C_2 be its optical centre; and let both eyes be adjusted for parallel rays; *i. e.*, the principal focus of each eye is situated upon the retina, as at the points A and A_2.

Rays coming from the point A will, after emerging from the eye E, proceed parallel to the straight line A C; they will be again refracted at the eye E_2 and brought to a focus in A_2, a point in the line C_2 A_2 which coincides in the diagram with the continuation of the line A C. Similarly, rays coming from B will be rendered parallel to the dotted line B C after their refraction at the eye E; and they will be brought to a focus at B_2 in the dotted line C_2 B_2 drawn parallel to B C.

It will be seen that the angle B_2 C_2 A_2 is equal to the angle B C A; and hence that the apparent magnitude of the object AB, as seen by the eye E_2, is as great as it would be if C_2 were as near to it as C is; that is to say, at a distance of rather less than $\frac{2}{3}$ of an inch in a real eye, which gives a magnifying power of 14 or 15 diameters.

Rays coming from D will proceed, after their refraction by the eye E, parallel to the line D C d; and it will be observed that only one of these rays can enter the eye E_2. This ray will, after refraction at E_2, meet the axis d_2 C_2 D_2, drawn parallel to D C d, in the point D_2.

The point D will thus be at the limit of the area of the retina of the eye E which is visible to the eye E_2.

The eyes in fig. 7 are supposed to be adjusted for parallel rays as before, but the distance between them is increased.

Rays coming from the points A and B will, after leaving the eye E, proceed parallel to the continuations of the lines A C and B C respectively; and such of them as enter the eye E_2 will be brought to foci in the lines C_2 A_2 and C_2 B_2, parallel to A C and B C respectively. It will be perceived that the angle B_2 C_2 A_2 is still equal to the angle B A C, so that the apparent magnitude of the object A B will be as great as formerly, although the distance between the eyes has been increased. Rays from D will proceed parallel to the dotted line D C d after they have left the eye E; and such of them as enter the eye E_2 will come to a focus in D_2 in the line d_2 C_2 D_2, which is parallel to D C d; but it will be observed that the uppermost ray which comes from D just clears the lower part of the pupillary margin of E_2, and that no light, coming from a point on the retina of E more distant from A than D is, would enter the eye E_2. Hence a point, such as D in fig 6, would not be visible to the eye E_2, placed as it is in fig. 7.

Thus if the eye E is adjusted for parallel rays, the apparent magnitude of objects situated on its retina will remain the same whatever distance the observer's eye may be from it; but the area seen by him will become less, the greater the distance is. In other words, the pupillary margin of the eye observed, as it appears magnified by refraction at the cornea, is, as it were, the frame in which the picture of the retina under observation is set.

The observer cannot at the same time adjust his eye for objects situated on the retina of the eye observed, and for the pupillary margin of its iris. Accordingly, when he sees its retina distinctly, he sees a diffuse image of the iris and pupil, each point at the pupillary margin of the patient's iris being represented by a circle of dispersion on the observer's retina, and the whole margin by a ring of some breadth, or even by a disk, made up of these circles. The outermost border of this ring corresponds with the circumference of the picture on the observer's retina of that portion of the retina observed, which is visible to him.

In fig. 7, a ray from the point D and one from the point A pass through the point p at the upper margin of the pupil of the eye E. These rays will, of course, pursue the same course after they have left the eye, whether we consider p as their starting point or regard them as coming from D and A respectively. After leaving the eye E, they will diverge as if they came from a point a little above and in front of p, corresponding to the apparent position of the latter as seen through the cornea; and they will form the extreme rays of the pencil, which, proceeding from p, and refracted at the cornea of E, and at that of E_2, enters the pupil of E_2. The rays of which this pencil is composed will form a circle of dispersion on the retina of E_2; and D_2 and A_2 are points at opposite sides of that circle, the point D_2 marking the limit of the diffuse image of the upper part of the pupil of E, and at the same time corresponding to the point D at the upper margin of the visible area of the retina.

If the antero-posterior axes of the two eyes coincide, if the point A is in the common axis, and if the pupil of E is not larger than that of E_2, it will appear brighter, ceteris paribus, than any other point on the retina of E; because the pencil, formed by rays proceeding from it, has its axis passing through the centre of the pupils of E and E_2 at right angles to the planes of both, while points in the vicinity of D will be faintly seen, because very little light from them enters the eye E_2.

In the case of eyes adjusted for parallel rays, as in figs. 6 and 7, the point A will appear equally distinct to E_2, whatever may be the distance between the eyes, because the same quantity of light from it enters E_2, and the magnitude of the image A_2 B_2 remains the same; but it will be seen, on comparing the diagrams, that while nearly as much light goes to B_2 as to A_2 in fig. 6, the quantity of light which goes to B_2 in fig. 7, is not nearly so great, although B is still far from the limit of the visible area.

If the pupil of the eye E were so much larger than that of the eye E_2 that a pencil coming from a point, such as B, should still be large enough to fill the pupil of E_2, the quantity of light sent to B_2; and consequently the apparent brilliancy of B might remain the same, even if the distance between the eyes were increased within certain limits; but, sooner or later, the point B would come to be faintly seen, previous to its total disappearance from the field of vision of E_2.

If the rays, coming from the point B were divergent instead of parallel, after leaving the eye E, the same thing might happen; indeed, the apparent brilliancy of B might be somewhat increased by a certain withdrawal of E_2 from E, because, in this case, the pencil coming from B, and entering E_2, might still be large enough to fill its pupil, while its obliquity to the axis of the pupil and the magnitude of the image A_2 B_2 would diminish together. We may apply to this case the principle always referred to*—that so long as the pencils coming from a given object, or its image produced by optical instruments, and entering the eye, are large enough to fill the pupil, the quantity of light contained in each pencil—or rather in the principal pencil and in each pencil, which enters the eye with a given degree of obliquity—will be

* Glasgow Medical Journal for July, 1860, p. 169.

exactly proportioned to the square of the angle which that object or image subtends at the eye, and consequently to the area of its image on the retina.

Hence the quantity of light, which falls on the point A_2 which is in the axis of the eye, being proportioned to the magnitude of the image A_2 B_2, the intensity with which A_2 is illuminated, will always be the same; whereas the point B_2 is illuminated by a pencil, the obliquity of which is becoming less and less the further E_2 is removed from E; and the intensity of its illumination will equal that formerly possessed by a point between A_2 and B_2. Thus, although we cannot give a greater intensity of illumination to a given point of the retina of E_2, by withdrawing it from E, unless the pupil of E is smaller than that of E_2, we may, by so doing, bring B_2 to a part of the retina which is more brilliantly illuminated, and B will accordingly appear brighter to the observer. This, however, is not a common case, and any increase in the apparent brilliancy of B would be hardly perceptible to the observer.

Supposing that the axes of the two eyes did not coincide, but that the axis of E_2, produced through the centre of the pupil of E, met the retina of the latter in some circumferential point, as is most frequently the case in practice, the point whose image would fall upon A_2 in the axis of E_2 would appear brighter to the observer than any other point in the visible area, both because its image is projected on the most sensitive part of his retina, and on account of optical reasons already indicated, although less light from that point might pass through the pupil of E than from some of the others. Although a pencil, coming from a point far from the centre of the retina, and passing through the pupil, passes obliquely, and has thus a less diameter than one from a central point, this cannot be strictly taken as the measure of the light it contains, for such a point is nearer the pupil than central ones; and, if it can be regarded as a source of light of equal intensity with them, a given area of the cross section of the pencil coming from it will contain more light, taken as it passes the pupil, than equal areas of cross sections of pencils coming from them taken at the same place.

In all cases, the point which occupies the centre of the observer's field of vision will appear brightest to him, and the parts towards the circumference will become more faintly seen and disappear successively as he withdraws his eye from the eye observed.

The main object of the observer is to have as large a field of vision as possible, and to see a large portion of any object within the field with the greatest possible clearness; and this will be attained by his approaching as near to the eye under examination as circumstances, and a due regard to the conditions of illumination with the instruments he may have at his disposal, will admit of.

The pupils of both eyes in the diagrams 6 and 7, are represented as widely dilated, and the distance between E and E_2 is less in both of them in proportion to the size of the eyes than it would be in most real cases; consequently the area of the retina of E, which is represented as visible to E_2, is much larger than what is generally seen. Not only so, but points in the neighbourhood of D send so little light from them into the observer's eye, and appear so confused with the indistinctly seen pupillary margin of the patient's iris, that they can hardly be reckoned within the distinctly visible area.

Helmholtz has fixed upon the centres of the circles of dispersion which would be formed in the observer's retina by pencils proceeding from points at the margin of the pupil of the eye under observation, as forming the ring bounding the portion of the observer's retina, which would receive distinct impressions of objects on that of the patient; and, going upon this principle, he shows that the visible area will be smaller than the patient's pupil, unless the observer's eye is within somewhere about half an inch from that of the patient, which is of course impracticable.* Under ordinary circumstances the size of the visible area is much less than that of the pupil.

When the eye under examination is adjusted for objects at finite distances, the rays reflected from a point on its retina, will, after passing through the refracting media, converge to a point at the distance for which the eye is accommodated.

Thus, if the eye E, in fig. 8, is adjusted, so that rays coming from A′ will be brought to a focus at A, rays reflected from A will converge toward A′ after they have left the eye.

If the eye E_2 were not adjusted for convergent rays, the rays coming from A would be brought to a focus in front of its retina, so that A would not be distinctly seen.

Supposing E_2 adjusted for parallel rays, and the biconcave lens L L, having the negative focal distance *c* A′, placed in front of it, the rays coming from A will be rendered parallel to one another after they have passed the lens, and will come to a focus at A_2 on the retina of E_2. If the observer's eye were at E_3, a stronger biconcave lens, such as L_2, having the focal distance *c′* A′, would require to be used in order to render the rays parallel, and they would then come to a focus at A_3.

Let E in fig. 9 be adjusted as before for the distance C A′; let E_2 represent the observer's eye adjusted for parallel rays; let the biconcave lens L L have the focal distance *c* A′; and let A and B be points on the retina of E.

Rays coming from A will converge towards A′ after they leave the eye E; they will become parallel, after passing through the lens, and they will come to a focus at A_2, on the retina of E_2, as

* Physiologische Optik: Leipsic, 1856, p. 178.

in fig. 8. Rays coming from B will converge towards B′ in the straight line B C B′ after they leave the eye, and the distance C B′ will be nearly the same as the distance C A′. After these rays pass through the lens, they will proceed parallel to the straight line c B′, drawn through c, the centre of the lens, and B′, the focus of the incident pencil; and they will be brought to a focus on the retina at B in the straight line C_2 B_2, drawn parallel to c B. In like manner we may determine the position of D_2, the point on the retina of E_2 occupied by the image of D, the extreme point on the retina of E, any light from which can enter E_2. It will be readily apprehended that the more myopic an eye is, or the shorter the distance for which it is focally adjusted, the more magnified will the objects on its retina appear when the direct mode of examination is followed, even though a concave lens is used. Thus, if E were adjusted for parallel rays, the angle subtended at C_2 by the image A_2 B_2 would be equal to that subtended at C by the object A B; while, when E is adjusted for the distance C A′, the angle subtended at C by the object A B is equal to the angle subtended at the same point by the image A′ B′; but the angle subtended at C_2 by the image A_2 B_2 is greater, being equal to that subtended at c, the centre of the lens, by the image A′ B′.

The more myopic the observed eye is, the smaller, ceteris paribus, is the area of its retina which is visible to the observer; because, while the objects on the retina appear more magnified, the pupil which limits the observer's field of vision will appear little, if at all, larger than it would if the eye were not myopic.

Fig. 10 is constructed on the same principles as fig. 9, the only difference being that the eye E_2 is further from E and nearer A, and that a stronger lens is consequently employed as an eye-piece in fig. 10 than in fig. 9. The object of the diagram is to show that when the eye under observation is adjusted for the distinct vision of objects at a given finite distance, the objects on its retina appear more magnified the further the observer recedes from it; while the visible area of course diminishes more rapidly on acccount of this circumstance than it would do if the observed eye were adjusted for parallel rays. In both diagrams, the image A_2 B_2 subtends an angle at C_2, equal to that which the image A′ B′ subtends at c; but this angle is greater in fig. 10 than in fig. 9, because the lens is nearer to the image A′ B′. When the focal adjustment of the eye under examination is such that rays, proceeding from a point on its retina, are still divergent after passing through the refracting media, objects situated on its retina appear less magnified, and the visible area is larger than it would be, if, other things being equal, the eye were adjusted for parallel rays. When, in examining such an eye, the observer recedes from it, the objects on its retina appear less magnified, the further he goes from it; and the visible area does not diminish so rapidly as it would if the eye were adjusted for parallel rays. The case, however, is a comparatively rare one. Objects situated far in front of the retina can be most conveniently examined by means of the direct method. They appear the more magnified the further back in the eye they are.

It must be recollected, that it is neither necessary nor advisable that the observer's eye should be as close to the eye observed when such objects are under examination, as it ought to be when his attention is directed to objects upon the retina, because the rays in the former case are more or less divergent when they leave the eye, their foci are situated in a virtual image which is nearer to or further from the observer, according as the object is nearer or further from the patient's cornea; and, in order to see that virtual image distinctly, he must not be nearer to it than the shortest distance at which he can read print. When the object is as far forward as the optical centre of the eye, its virtual image seen by the observer is as far forward as itself.

Opacities in the vitreous humour or crystalline lens may be rendered apparent in two ways, either by concentrating the light upon the surface of the opaque body from which it is reflected, and sent to the eye of the observer, or by illuminating the fundus oculi strongly, when the form of the opaque body can be perceived in consequence of its intercepting the light on its return from parts behind it. Both plans may be followed with advantage in many cases; in some, one is to be preferred to the other. It may be stated in a general way that when the opaque body is situated far forward in the eye, and when its surface has a considerable reflecting power, the circumstances are favourable to the former method of examination; when, again, the opacity is at once deeply seated, and of a dark colour, we may be compelled to employ the latter alone.

In both cases, the observer must be at such a distance from the patient that he can adjust his eye for the distance of the virtual image, which we may suppose to be formed by the foci of rays reflected from the opaque surface, and refracted by the patient's eye, on the assumption that the opaque body does reflect light; otherwise he will not see it distinctly.

Thus, if the observer wishes to examine an incipient cataract, and places himself as close to the patient's eye as he would do if his object were to see the retina, he will obtain no distinct impression of the site and form of the opacity; but, as he gradually withdraws his eye from that of the patient, portions of the pupil will begin to appear dark, and these dark spaces will become more and more distinctly defined against the illuminated ground, until he will be able to form a distinct idea of the position and extent of those portions of the lenticular substance which do not transmit the light, when the distance has come to be eight or ten inches. The reason of this is, that when the eye of the observer is close to that of the patient, he sees an image of the retina more or less distinctly according to the focal adjustment of his own eye, and according to the extent to which the patient's lens is affected with cataract. It may be that he cannot discern the opacities at all, because in virtue of the refracting power of the patient's eye, light is sent into the eye of the observer from points directly behind the opaque portion of the lens, the effect of the opacity being rather to diminish the quantity of light sent out from each point of the field of vision, than to intercept all the light sent from any one of them. In this case, the observer is as it were looking at the retina through an apparatus similar, in certain respects, to that known as a *spot lens.* If, again, the observer is at such a distance that he can adjust his eye for the virtual image of the opaque body, we may imagine a plane to pass through that body at right angles to his visual axis. Through certain points in this plane light is passing in various directions from behind, and we may regard such points as foci—through others no light passes. If the observer's eye is suitably adjusted, the light proceeding from such of the former set of points as lie within his field of vision as from foci, will be brought to foci on his retina, and he will thus see a well-defined illuminated image of the patient's pupil with the opacities appearing like dark spots or streaks upon it, just as he sees the page of a book and the print upon it distinctly, not by means of light coming from the black letters on the page, but by means of light coming from points in the surrounding white surface.

2. *Indirect method—Observation of real inverted image.*—Let E, fig. 11, represent an eye under examination having its posterior principal focus at A on its retina; let E_2 be the observer's eye adjusted for the distance C_2 A′; and let L L be a biconvex lens, the principal focal distance of which is equal to *c* A′.

Rays coming from the points A and B will proceed parallel to the axes A C and B C respectively, after they have left the eye E. After these rays have been refracted at the surfaces of the lens L L, they will converge to real foci nearly in the points A′ and B′ in the axes *c* A′ and *c* B′, drawn parallel to A C and B C respectively, the distances of these points from *c* being equal to the principal focal distance of the lens.

A real inverted image of the object A B will thus be formed in the air at A′ B′, and the size of the image A′ B′ will be to that of the object as the distance *c* A′ is to the distance A C.

In order that the observer may see the inverted image at all, his eye must be so placed that some of the light which has passed through points in the image A′ B′ may enter his pupil; and, in order that he may see it distinctly, his eye must be adjusted for the distance of the image. If this is the case, the rays which have crossed one another in A′ and B′, and which enter E_2, will be brought to foci on its retina at A_2 and B_2 in the axes A′ C_2 A_2 and B′ C_2 B_2 respectively.

The position of the point D′, corresponding in the image to D′ on the retina, may be found in the same way as the positions of A′ and B′. It will be seen that only one of the rays which have crossed one another at D′ enters the pupil of the eye E_2, and is transmitted to D_2 on its retina; so that D is a point at the circumference of the area of the retina of E which is visible to E_2, even although real images of points further from A than D is, may be projected by the lens; the reason being that the rays which have crossed one another in the images of such points will not radiate freely in every direction as they would do from a real surface, but their direction lines will be confined to a certain angle of divergence determined by the size of the pupil of E, the distance between it and the lens, and the focal distance of the latter.

The area of the retina under examination, which is visible to the observer, is bounded by the pupillary margin of the observed eye as seen magnified, and more or less indistinctly through the lens. The point D_2 in fig. 11, on which the image of D′ or D falls, will be at the upper or outer margin of the circle of dispersion which would be formed on the retina of E_2 by rays proceeding from the point *p* at the lower margin of the pupil of E. Such rays would pass through the lens L L, and would be rendered less divergent in consequence, so that their focus would be thrown further back than *p*; but the eye E_2 is adjusted for the image A′ B′; hence rays from *p* would cross one another, and come to a focus in front of the retina of E_2 after entering that eye. A circle of dispersion would thus be formed, and the lowermost ray of the pencil which enters the eye E_2, would go to the uppermost point of the circle, and that ray would obviously coincide in its direction with the ray which is represented in fig. 11 as touching the point *p*, in its passage from D to D_2.

In fig. 12 the lens is represented as removed to a greater distance from the eye E than it is in fig. 11, the focal adjustment of the eyes E and E_2 remaining the same. As the rays coming from the points A and B and refracted after leaving E, are still parallel to the axes A C and B C respectively, the image A′ B′ will be at the same distance from the lens as it was in fig. 11, it will still subtend the same angle at *c* that the object A B subtends at C, and it will have the same magnitude which it had before; while, if the eye E_2, is placed at the same distance from A′ B′ in figs. 11 and 12, in order that the image may be distinctly seen by it, the same space will be occupied on its retina by the image A_2 B_2 in both cases.

If we now turn our attention to the area of E's retina visible to E_2, and which has the point D upon its circumference, it will be observed that it is larger in fig. 12 than in fig. 11. The visible area will now appear to be bounded by the margin of the lens, instead of the margin of the pupil; the point *p* will be out of sight, and only a part of the pupil of E, which will appear as large as the lens, will be visible to E_2. This occurs when the distance between the eye E and the lens is somewhat greater than the principal focal distance of the latter. The visible area has then attained its maximum in point of extent; but if the lens is withdrawn still further from the eye under examination, the pupillary margin will again come into view when the distance has increased to a certain point, the visible area will become contracted in its dimensions, and the pupil will appear to decrease in size the further the lens is withdrawn from E. When this happens, the observer sees an inverted image of the pupil projected between his eye and the image A′ B′ by the lens; and he looks at the image A′ B′, as it were, through this image of the pupil, as he would through an aperture.

In figs. 13 and 14, the eye E is supposed to be adjusted for the distance C A′ = $2\frac{5}{8}$ inches; the posterior principal focus is, consequently, further forward than the point A. Let the lens L L, fig. 13, be placed in front of E, at a distance of 2 inches from A′, and let its focal distance be 1 inch.

Rays coming from the points D, A, and B, will converge towards the points D′, A′, and B′, in the axes D C D′, A C A′, and B C B′ respectively, after they leave the eye E. After these rays have been refracted at the surfaces of the lens L L they will come to foci in the points D″, A″, and B″, which are situated in the axes, *c* D′, *c* A′, and *c* B′; and the distance of these points from $c = \frac{2}{3}$ inch may be found by Formula ii., Part I.*

An inverted image of the object A B will thus be formed at A″ B″; and in order to see this distinctly, E_2, if it is adjusted as in figs. 11 and 12, must be at the same distance from A″ B″ that it was from A′ B′ in them.

In fig. 14, the lens has been brought forward till the distance between its centre and A′ is $1\frac{1}{8}$ inch; and the distance between *c* and the image A″ B″, found as in the case of fig. 13, will be $\frac{9}{7}$ of an inch.

The image A″ B″ subtends the same angle at *c*, in figs. 13 and 14, with the image A′ B′; and this is larger in fig. 14 than in fig. 13. The image A″ B″ is also larger in fig. 14 than it is in fig. 13; although, in consequence of its being nearer the lens in fig. 14, this increase is not exactly proportioned to the increase in the magnitude of the angle subtended at *c* by the image A′ B′. Were the lens removed from E till *c* coincided with A′, the image A″ B″ would be as large as A′ B′, and would coincide with it.

It will be seen, on inspecting the diagrams, that the visible area, on the circumference of which the point D is situated, is larger in fig. 14 than in fig. 13; although, in consequence of the increase in the size of the image A″ B″ the area does not increase in size so rapidly as it would otherwise do.

* Glasgow Medical Journal, July, 1860 p. 160.

When the eye under observation is myopic, as in figs. 13 and 14, the image A″ B″ is smaller in proportion to the object A B than it would be if the eye were adjusted for parallel rays, so long as the distance between the eye and the lens is less than the sum of the anterior principal focal distance of the eye and the principal focal distance of the lens. When the distance equals the sum of these focal distances—that is to say, when the lens is at a distance from the cornea equal to its own focal distance plus ⅗ of an inch, or rather less—the image will be proportioned to the object as the focal distance of the lens is to the posterior focal distance of the eye, measured from the optical centre, or the anterior, measured from the cornea, whatever the state of focal adjustment of the eye may be. And when the distance between the lens and eye is greater than this, and the eye is myopic, the image will be larger, in proportion to the object, than the focal distance of the lens is in proportion to that of the eye.

If the eye is hyperpresbyopic, so that rays coming from a point in the retina, still diverge after passing through the cornea, the image projected by the lens will be larger in proportion to the object than the focal distance of the lens is in proportion to that of the eye when the distance between eye and lens is less than the sum of their focal distances, and smaller in proportion when the distance is greater.

In all cases, the visible area increases in size as we withdraw the lens from the patient's eye, until the image of the pupil seen by the observer appears to him as large as the lens.

These differences in the real or apparent size of the image seen by the observer, according as he approaches or withdraws from the patient in the direct method of examination, and according as the lens is advanced or withdrawn in the indirect, are not very perceptible, except in cases of extreme myopia or hyperpresbyopia. In general, it will be found that an eye exposed to the strong light thrown into it by the ophthalmoscope has a tendency to fall into a state of adjustment for distant objects, more especially if atropine has been employed to dilate the pupil; at least this opinion seems to be commonly held by the most experienced observers. The posterior principal focus is then very nearly upon the retina; and rays coming from a point near the centre of it will pursue lines of direction very nearly parallel to one another after they leave the eye. When this happens, we may find the relation between the size of the object and inverted image by dividing the focal distance of the lens by that of the eye, whatever the distance between them may be; thus, a two-inch focus lens will give a magnifying power of about three diameters.

It may happen, however, that the retina is considerably behind, or in front of, the posterior principal focus of the eye; or there may be objects at once within the field of vision which are situated in different planes within the eye—some further forward, and others further back—and we may wish to form an opinion with regard to their relative magnitude and position.'

The inverted images of these objects will be projected in various planes, those corresponding to the objects furthest forward in the patient's eye being nearest to the observer, and furthest from the lens. The observer cannot see them all with perfect distinctness at the same time, because he cannot adjust his eye for the whole of them at once; but, unless the distance between the images is very considerable, he may see them sufficiently well for all practical purposes at the same time; just as we can see two objects together, one at ten inches distance, and another at twelve inches. When the distance between the optical centre of the lens and that of the eye under observation is equal to the sum of the principal focal distance of the former and the anterior principal focal distance of the latter; when, for example, a two-inch lens is held from $2\frac{1}{2}$ to $2\frac{2}{3}$ inches in front of the patient's cornea, the absolute size of the inverted images of all objects situated within the eye would be similarly proportioned to the objects, if the eye possessed but one refracting surface like those in the diagrams. As it is, the statement may be applied with sufficient accuracy to the images of such objects as are situated behind the crystalline. In the case supposed, we should have all the inverted images magnified about three diameters, or rather more, with respect to the objects. Those of the images which are nearer the observer would, of course, appear larger to him than those further off; just as they would if they were real objects, although their real magnitudes might be the same.

It has been already stated, that if we increase the distance between the lens and eye, the inverted images of objects behind the posterior principal focus of the latter will increase, while those of objects in front of it will diminish in size; and, accordingly, if we diminish the distance, the inverted images of objects in front of the posterior principal focus of the eye will increase, and those of objects behind it will diminish in size. Hence the inverted image of an object within the eye will be more magnified the further forward it is in the eye, when the distance between eye and lens is less than the sum of their principal focal distances; and it will be more magnified the further back the object is, when the distance between eye and lens exceeds the sum of their focal distances.

When the indirect method of examination is pursued, we can obtain a view of different parts of the patient's retina successively, without causing the patient to move his eye, and without changing our own position, by simply moving the biconvex lens held in front of the patient's eye.

Let E, fig. 15, be the eye under observation adjusted for parallel rays; and let A be a point on its retina. When the lens L L is held so that its axis coincides with the antero-posterior axis of the eye E, the rays which have proceeded from the point A, and which pursue lines of direction parallel to the axis A C after they have left the eye, will be brought to a real focus at A′ in the continuation of the same axis produced through *c*, the centre of the lens; and the distance *c* A′ will equal the principal focal distance of the lens. From this point the rays will diverge and proceed towards the observer's eye E_2, where such of them as enter it will come to a focus in A_2, if the eye is properly adjusted for the point A′.

If the lens is now brought down to the position *l l*, so that its centre is at *c*′, the rays coming from A will proceed as before, until they have been refracted at the lens; they will then come to a focus and cross one another in a, a point in the line of direction of the ray which passes through *c*′, and which is the lowermost ray of the pencil proceeding from A, and passing through the pupil of E. This ray is also the only one which, proceeding from a, enters the eye E_2; and it will meet the retina of that eye at a_2 in the dotted line a C_2 a_2.

The point in the image corresponding to the point A on the retina of E will thus have moved down from A′ to a, as the lens has been moved from the position L L to the position *l l*; not only so, but it will be observed that whereas A′ will appear to E_2 to be in line with *c*, the centre of the lens *a* will appear in line with a point in the lens considerably below *c*′. Thus the inverted image of a part of the retina moves in the same direction as that in which the lens is moved; and any one point in the image will appear to move faster in that direction than the lens does, provided the object is not behind the posterior principal focus of the eye under examination.

In fig. 15, where the lens is close to E, the field of vision of E_2 is limited by the pupillary margin of E seen somewhat indistinctly through the lens in the form of a magnified erect virtual image. The imaginary position of this virtual image of the pupil moves in the opposite direction to that in which the lens is moved, so that the image of A will not only have moved absolutely down, as the lens has been moved down; but it will appear, as it were, on a lower part of the lens, and at a lower part of the field of vision; indeed, it might be shown that the point a, instead of occupying the centre of the field as A′ did, is at the lower margin of the field as altered by the change in the position of the lens. Thus, in the circumstances represented in fig. 15, a higher part of the inverted image, corresponding to a lower part of the patient's retina, is brought into view when the lens is moved down.

But this is by no means universally the case; and it is of considerable importance to be aware of the conditions under which the state of matters may be completely reversed.

When the lens is withdrawn to a distance somewhat greater than its own focal distance from the pupil, the observer's field of vision has reached its maximum; and it is bounded, not by the magnified image of the patient's pupillary margin, but by the margin of the lens. If the object is situated in front of the posterior principal focus of the eye under examination, as the retina of a hyperpresbyopic eye is, its inverted image will be further from the lens than the principal focus of the latter; and when the lens is moved down, the image will move down further than it does; and it will consequently appear to move towards the lower margin of the lens, and towards the lower margin of the field of vision bounded by the margin of the lens. The same thing will happen when the object is in the posterior principal focus of the patient's eye; because, although the inverted image is then at a distance from the lens equal to the principal focal distance of the latter, and moves down just as much as it moves down (see fig. 15), it will appear to the observer to move more, in virtue of the laws of perspective. When, however, the object is behind the posterior principal focus of the patient's eye, as the retina of a myopic person is, its inverted image is nearer to the lens than its principal focus; and when the lens is moved down, the image does not move down so much, and it will not appear to the observer to move so much as the lens, unless either his distance from them is very small relatively to the principal focal distance of the lens, or the image is very nearly as far from the lens as its principal focus is. In consequence of this, the image, though it really moves down, will come opposite a higher part of the lens, and will therefore occupy a higher part of the field of vision than it did before.

When the lens is so far removed from the eye under examination that the observer's field of vision is bounded by an inverted image of the patient's pupil projected between the observer and the lens, that image will be further from the lens than the inverted images of objects behind the pupil. It will therefore move down further than they will, when the lens is moved down, and they will all come to occupy a higher position in the observer's field of vision than they formerly did.

In all cases, the further forward an object is in the eye under observation, the further will its inverted image be from the lens and the nearer to the observer; and when the lens is moved, its image will move more than those of deeper seated objects. Accordingly, when various objects which are situated in different planes are in the observer's field of vision at the same time, their inverted images will have apparent motions with respect to one another when the lens is moved. Besides this, the images of all objects will appear distorted, as they seem to approach the margin of the lens on account of spherical aberration.

A general expression of the conclusions to be drawn from the statements made with regard to the phenomena observed on moving the lens employed in the indirect method of examination, may be given as follows:—

1. When the lens is held at such a distance from the eye under observation that the observer's field of vision is bounded by an erect magnified image of the pupillary margin, the inverted images of objects situated within the observed eye will move towards that side of the visible area towards which the lens is moved, and the images will move more rapidly the further forward the object is situated in the eye.

2. When the lens is held at such a distance that the visible area appears bounded by the margin of the lens, the inverted images of objects situated within the eye, and anterior to its posterior principal focus, will move towards that side of the field of vision towards which the lens is moved with greater rapidity, the further forward the objects are; and those of objects situated above a small distance behind the posterior principal focus will appear to move towards the opposite side of the field of vision with greater rapidity, the further back the objects are.

3. When the lens is held in such a manner that the field of vision is bounded by an inverted image of the patient's pupillary margin projected between the observer and the lens, the inverted images of all objects situated behind the pupil will appear to move towards the side of the field of vision opposite to that towards which the lens is moved with greater rapidity, the further back the objects are situated.

If it should happen that an inverted image of an object within the eye under examination should be projected between that eye and the lens (which might possibly be the case if the eye were affected with staphyloma posterius in a very advanced stage, and if the lens were held at a considerable distance from it), the observer might see an image of this image magnified by the lens, which would have a real motion in the direction opposite to that in which the lens is moved; while its apparent motions in the field of vision would be such as those predicated in the last three paragraphs of the inverted images of objects situated behind the posterior principal focus of the eye projected between the lens and the observer.

The extent of the area of the patient's retina, which can be seen by the observer when the indirect method of examination is employed, depends upon the diameter and the focal distance of the biconvex lens, and upon the distance at which it is held from the eye under examination, as well as upon the size of the pupil and state of focal adjustment of the eye itself.

Supposing the observer's field of vision to be bounded by the margin of the lens (in which case the maximum has been reached), and the inverted image of the patient's retina to be magnified three diameters, that portion of the image which is seen by the observer will appear to him as large as the lens; but it will really be somewhat smaller—by a fifth or a sixth part perhaps—because the lens is further off than it is; and the diameter of the visible area of the patient's retina will consequently be somewhat less than a third of that of the lens, provided the conditions for the illumination of so large an area are simultaneously fulfilled.

If the observer makes use of a biconvex eye-piece to enable him to see the inverted image from a shorter distance, so that it will have a greater apparent magnitude, he will find that the visible area contracts its dimensions, as he gets nearer the lens held before the patient's eye. Thus, if E_2, figs. 11 and 12, were nearer to the image A′ B′ than it is, no light from D would enter its pupil.

The apparent brightness of the central parts of the observer's field of vision will always be the same, so long as the pencils of light coming from points in the inverted image are large enough to fill his pupil. The nearer the observer comes to the inverted image, the less will be the diameter of pencils coming from points in it as they reach his pupil. Supposing the pupil of the observer and that of the eye observed are of equal diameter, the maximum apparent brightness of a point in the centre of the field of vision will always be reached when the observer's eye is as far from the inverted image as the observed eye, provided the image is thrown between the lens L L and the observer. If the point in the observed eye which corresponds to the central point of the observer's field of vision is not behind the posterior principal focus of that eye, the observer may approach as near to the inverted image as the lens L L is, without a diminution taking place in the apparent brightness of the central point, provided the pupil of the observed eye is as large as that of the observer. Under all ordinary circumstances, the observer is much further from the inverted image than this. The circumferential parts of the field of vision appear less bright than the central ones, when the indirect method is employed, as they do in the case of the direct method.

Opacities in the media may be viewed by the indirect method as well as by the direct, when the observer places himself at such a distance from the lens L L that he can accommodate his eye for the place which would be occupied by the inverted image of an object situated in the same plane with the opacity, if such an object were seen by means of light coming from its surface. On this account, the further forward the opaque body is in the eye under observation, the further must the observer withdraw himself from the lens, and he must also see that the lens is far enough from the eye under observation. If the opacity is in the crystalline, the distance of the lens from the patient's eye ought to be greater than its own principal focal distance. It will be found, however, that the direct method is the simplest and most convenient for the examination of all objects situated pretty far forward in the eye.

3. *Comparison of direct and indirect methods.*—The chief advantage which the indirect method has over the direct is,

that by following it, we can see a much larger portion of the fundus oculi at the same time, with a greater brilliancy for parts between the centre and circumference. We thus get a better idea of the relative positions and magnitudes of objects than we can easily do by a detailed examination of them successively. It may be added that certain contrasts of colour, &c., come out more distinctly and strongly when a low magnifying power is used; and this applies to the ophthalmoscope as well as to the microscope. Objects on the retina are usually seen magnified some fourteen or fifteen diameters when the direct method is employed, whereas with the lenses commonly made use of in the indirect method, we have a magnifying power of from two to five diameters.

We may also magnify the inverted image to almost any degree by employing a combination of lenses similar to that in a compound microscope, instead of the simple lens L L held in the hand of the observer; but it must be remembered, that the visible area of the patient's retina will be diminished in proportion. Helmholtz has pointed out that it is difficult to see a larger area by means of the indirect method than we can by means of the direct with the same magnifying power; and that, even although we might do so by a particular combination, the advantage in point of extent of area seen would be gained at the expense of a certain indistinctness in the image, and difficulty of handling the apparatus, inseparable from the use of a couple of convex lenses of short focal distance, and comparatively wide aperture.*

By using particular forms of stationary instruments, such as those of Liebreich and others, in which the lenses are supported in a system of tubes or a framework, so as to admit of their distances from one another and from the patient's eye being mechanically adjusted, we might obtain a very considerable magnifying power with pretty good definition by the indirect method. However, supposing the observer's pupil and that of the patient to be of equal diameter, and the patient's eye to be adjusted for parallel rays, or for rays diverging from an object at a finite distance, we could not see even the central point of the visible area of the retina with so great an apparent brilliancy as we could by means of the direct method, if the magnifying power were greater in the case of the indirect, and the illumination the same in both; because then the pencil coming from the central point of the image seen by the observer will not fill the whole of his pupil, nor so great a part of it as it would do in the case of the direct method. A general statement of this kind is made by Helmholtz in the pamphlet just referred to. It appears to me, however, that if the patient's retina were in front of the posterior principal focus of his eye, or if his pupil were larger than that of the observer, it would be possible to obtain a somewhat greater

* Beschreibung eines Augenspiegels, p. 27.

magnifying power with an equal apparent brilliancy by means of the indirect method.

If the patient's eye were myopic, and his pupil not larger than that of the observer, it would be possible for the observer to see the central point of the visible area with greater apparent brilliancy by the indirect method than by the direct, but the magnifying power would require to be less.

In ordinary practice it will be found best to employ the indirect method when we wish to see a large area, and the direct when we wish to see the objects much magnified, so as to examine their details minutely; for, although the indirect method may answer the latter purposes too, and has the advantage, as Helmholtz admits, of enabling the observer to adjust the apparatus, so as to suit all the various conditions of focal adjustment which present themselves in the eyes observing and in those observed, by simply altering the distance between the lens L L and the observer's eye-piece, without changing the lenses themselves, while it is necessary to change the concave lens used in the direct method until a suitable one is found; still, as he remarks, the difficulty of directing the axes of the lenses properly, taken in conjunction with the want of perfect steadiness on the part of the patient and observer, renders the employment of so complicated a combination inconvenient.

When the ophthalmoscope and the head of the person examined are both fixed, as in the case of Liebreich's instrument, and when the person examined has the power of steadily fixing his eye upon a particular object for a considerable time, these complicated arrangements may be employed with advantage; but the time and trouble requisite for their proper adjustment make them less adapted for the purposes of ordinary diagnosis than for detailed scientific examinations.

In ordinary practice, the simpler the instrument is the better; and, in many cases which come under observation, the patient's eye is so unsteady that a fixed ophthalmoscope cannot be employed. The direct method is perhaps less embarrassing to a beginner than the indirect, because he is not perplexed by the inversion of the image, and by seeing images of the flame of the lamp, or of the reflector, caused by reflection at the surfaces of the lens. Some persons seem to acquire a facility in employing the one method, and others a facility in employing the other, with greater or less readiness; but a great deal depends upon having once got a distinct view of the image, whether erect or inverted, and after that upon habit. It is of great importance to be familiar with both methods; for, by employing both, the observer will be less liable in many cases to misinterpret what he sees, and to overlook appearances of some pathological importance, than he would be if he only employed one.

There are cases in which we cannot employ the direct method of examination, on account of the extreme myopia of the patient's eye. Thus the image A′ B′, figs. 9, 10, 13, and 14, will generally be behind the observer's eye, even when he is at such a distance from the patient as is usual when the indirect method is employed; but if the patient's eye were so myopic as to project A′ B′ at a distance of three or four inches from itself, the observer would find it impossible to get his eye near enough to that of the patient to see an erect image of his retina with any ophthalmoscope and concave lens likely to be at his disposal; and lenses of very short focus do not make good eye-pieces. He might, no doubt, succeed by placing a strong concave lens in front of the patient's eye, between it and the ophthalmoscope; but this would contract his field of vision, and be disadvantageous in various ways.

But the indirect method may be applied to the most myopic eyes. It is sometimes possible to see the image A′ B′ tolerably well, even without a biconvex lens to bring it back to A″ B″—figs. 13 and 14. This would be the case, for example, if the distance of A′ B′ from E were as it has been represented, for the sake of convenience, in these diagrams, and even if it were considerably greater.

PART IV.—MODES OF SIMULTANEOUSLY FULFILLING THE CONDITIONS OF ILLUMINATION AND PERCEPTION OF OBJECTS WITHIN THE EYE.

Whether we make use of the direct or the indirect method of examination, our object is to see what we are looking at distinctly, and to have as large a field of vision as we can obtain compatibly with this. The first requisite for distinct perception is, that the observer should have his eye accurately adjusted for the image which he sees; and the second is, that the apparent brilliancy of that image—depending on the illumination of the object and on the proportion between the amount of light which returns from it to the observer's eye and the apparent magnitude of the image—should be sufficient. As to the extent of area seen, that will depend upon the relation between the apparent magnitude of the patient's pupil, or of the lens, the circumference of which bounds the observer's field of vision, and the apparent magnitude of the image of an object of given size which is seen by the observer, and upon the proper illumination of the whole field of vision.

The larger the patient's pupil is, the more light will get into his eye, under ordinary circumstances, and go to each point of the illuminated area of the fundus oculi; the more will get out again after reflection at the bottom of the eye; and, in many cases, the greater will be the proportion of the light so thrown out which reaches a given point on the observer's retina. Besides all this, the observer's field of vision will be larger, ceteris paribus, the larger the pupil of the patient is, except when it is bounded by the margin of the lens in the indirect method of examination.

Thus, it is always of advantage to make use of atropine for the purpose of dilating the pupil, and keeping it dilated under exposure to light, except where circumstances forbid its employment.

When the objects to be seen are situated on the fundus oculi, and the direct method of observation is made use of, the observer ought to be as close as possible to the eye observed, if the latter is not hyperpresbyopic, because his field of vision will be larger; while, if the eye is at all myopic, he will be able to employ a weaker concave lens the nearer he is to the patient, and this is a great advantage in itself. It may happen that the observer can dispense with the concave lens altogether, and if so, it is all the better.

The means of illuminating the fundus oculi by a reflecting apparatus placed close in front of it, have been already discussed in Part II.

If we place ourselves in the position of a patient, and observe the reflection of the flame in such an ophthalmoscope as Helmholtz's, it appears much fainter than that in the case of an opaque polished reflector; and, accordingly, the illumination of the fundus oculi is fainter.

Again, a large portion of the light returning from the eye observed is reflected from the surfaces of the glass plates in Helmholtz's ophthalmoscope, and does not reach the observer's eye; so that we might expect that the apparent brilliancy of the image seen by the observer would not be so great when such an instrument is used, as when we have recourse to an opaque reflector. If, however, we take the effect of the hole in the opaque reflector into account, it will be found that this is not always the case. All the light which goes direct from the reflector to a given point on the fundus of the observed eye, comes from a given area of the reflecting surface; and if the bundle of rays passing from that portion of the reflector to the point in question has a sufficiently large diameter to fill the patient's pupil, all the light which returns from the point will fall upon the same portion of the reflecting surface, and none will enter the observer's eye; consequently, the greater the proportion of the returning light which goes through the hole in the reflector to the eye of the observer, the smaller will be the area of the reflecting surface from which light is sent to the point on the observed fundus oculi, and the less intense will be its illumination. This holds good for any point of the patient's fundus oculi which is within the observer's field of vision. Taking all these circumstances into account, Helmholtz has shown that an apparent brilliancy of the image seen by the observer, equal to that which can be got when perforated opaque reflectors are employed, may be obtained by the use of his instrument, when the direct method of examination is made use of, if the patient's pupil is not larger than the observer's;

but if it is larger, the opaque reflector has the advantage in this respect.*

The light reflected from Helmholtz's ophthalmoscope is less dazzling to the eye under examination than that reflected from stronger reflectors. Hence it can be borne for a greater length of time, and is better adapted for prolonged examinations; while, at the same time, it does not cause the pupil to contract to so great a degree in cases where atropine has not been used.

A reflection from the patient's cornea, causing the appearance of an image of the flame or reflector which occupies the centre of the pupil when we wish to examine the parts about the macula lutea, is a great obstacle to the distinct perception of the fundus oculi. When the pupil is contracted, this image may fill nearly the whole of it. The difficulty of adjusting the eye for an object which is faintly illuminated in comparison with others, and of which we can see but a small part, is very great; and we have an involuntary tendency to adjust our eyes as far as possible for the brilliant reflection, instead of the patient's retina. If, however, the pupil is so large that we can see a considerable portion of the fundus past the side of the reflection, we can accommodate our eye for it with greater facility; and this being done, the reflection, instead of being bright and well-defined, assumes a diffuse, stellate appearance, and becomes so faint that we may perhaps be able to see right through the middle of it. The light reflected from Helmholtz's ophthalmoscope is polarised to a greater or less extent, and a consequence of this is, that a comparatively small portion of what is reflected from the cornea reaches the observer's eye, and the reflection appears faint.

In order to use this instrument to the greatest possible advantage, it must be held at a certain angle to the direction of the light incident upon it varying according to the number of glass plates.

In all these cases the flame of the lamp will be to one side, and a little in front of the patient; and it may be advisable to shade his face from its direct light by means of a screen.

Zehender's ophthalmoscope has also the merit of diminishing the apparent intensity of the reflection from the cornea, especially when it is held in a particular way, which may be found experimentally. A certain advantage may be gained in point of intensity of illumination, by the employment of such combinations as enable us to throw a large amount of light into the eye under observation, even though that light may be distributed, in the first instance, over a correspondingly larger area and a greater

When one plate is employed, the proper angle of incidence is	70°
Three plates, - - - - - - -	60°
Four plates, - - - - - - -	56°†

* Physiologische Optik., p. 183.

† Helmholtz—Beschreibung eines Augenspiegels, p. 17.

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area than that which the observer sees; not because the *primary* intensity, if I may use the expression, is greater, but because there is more light reflected to and fro in the interior of the eye; the visible area being illuminated, first, by light which has come directly through the refracting media from the reflector; and secondly, by light reflected from other parts of the fundus oculi. The additional intensity so gained will, however, be slight in general.

When a perforated opaque reflector is used, the thinner it is the better, because the observer has to look obliquely through the canal in its substance; and the longer the canal is, the narrower, under such circumstances, will the practically efficient aperture be. Metallic reflectors, such as Zehender's, have the advantage in this respect, because they can be made very thin.

For the examination of objects seated far forward in the eye, by means of light reflected from their surfaces, the best plan is to dispense with the reflector altogether, and to concentrate the light of a flame, placed a little in front and to one side of the eye, upon the object, by means of a biconvex lens of short focal distance. When the object is not perfectly opaque, a larger proportion of the incident light is reflected if it falls obliquely upon it, and the object may thus be better seen; while, at the same time, the observer will not see light reflected from the fundus oculi, unless his eye is nearly in the line of the incident rays, and the apparent brilliancy of the object under examination will not suffer from contrast. This method is well adapted for the examination of incipient cataracts, the opaque portions of lenticular substance, and the position of the different planes in which they are situated, coming well out in relief. Its employment was recommended long before the invention of the ophthalmoscope, but it seems to have come into more general use of late.*

When the indirect method of examination is employed, the problem—how may we combine good illumination of the object with distinct perception of it by the observer, to the greatest advantage, becomes a rather more complicated one in theory, if not in practice.

Helmholtz shows that, when light goes from every point of the flame to every point of the reflector, and from every point of the reflector to every point of the biconvex lens, and from every point of the lens to every point of the pupil of the observed eye, we have the largest possible area of the fundus oculi illuminated with the maximum intensity; the whole lens then appearing to the observed eye as brilliant as the flame itself, or very nearly so. This is attained when the image of the flame produced by the concave reflector employed coincides with the lens in size and position, and when the image of the reflector, produced by the

* See Mackenzie on Diseases of the Eye: London, 1830, p. 571; and Liebreich in Gräfe's Archiv. Bd. I., Abt. II., s. 351.

foci of rays coming from the reflector, and refracted at the lens and at the cornea of the observed eye, coincides in size and position with the pupil. The distance of the lens from the pupil will, in this case, be about equal to its own principal focal distance, when that is short in proportion to the distance between lens and reflector, which last must nearly equal the sum of the focal distance of the lens and the distance for which the observer can most easily accommodate his eye. By taking the diameter of flame, reflector, lens, and patient's pupil, into account, together with the conditions already mentioned, and the magnifying power desired by the observer, we may calculate what the focal distances of lens and reflector, and the distance of the flame from the latter, ought to be. Thus, Helmholtz shows that all the conditions would be fulfilled with a flame of 15 millimètres in diameter, placed at a distance of 105 mm. from a concave reflector, having a diameter of 25 mm., and focal distance of 70 mm., placed at a distance of 210 mm. from a biconcave lens of 30 mm. aperture and 60 mm. focal distance, placed in front of an eye, the pupil of which is 10 mm. in diameter. The distance between the lens and the pupil would then be 84 mm., rather greater than the focal distance of the lens itself; and this being the case, from the position of the observer close behind the reflector, his field of vision would be bounded by the margin of the lens. If we were to draw lines from the centre of the observer's pupil to the circumference of the lens, and regard the course which they would afterwards take, supposing them to be rays of light, they would intersect one another at a point very nearly in the same plane with the image of the reflector projected by the lens, or a little in front of the optical centre of the observed eye, where they would cross one another; and they would eventually strike the fundus oculi at points very nearly in the circumference of the illuminated area, corresponding to the diffuse image of the illuminated lens. Rays coming from these points, and emerging from the observed eye, would proceed in the opposite direction—namely, towards the observer—but the direction lines of some of them would coincide with the lines first mentioned; and these rays would appear to the observer to come from the margin of the lens, or from points at the circumference of his field of vision, which would thus coincide almost exactly with the illuminated area of the fundus oculi under examination.

A somewhat different mode of illumination adapted to the indirect method of examination is represented in fig. 4.* An intensity of illumination equal to that obtained in the manner recommended by Helmholtz, might be secured in this manner also, if the image A_3 B_3 were in the plane of the pupil, and as large as it, and if light from every point in that part of the

* Glasgow Medical Journal for July, 1860.

image A_2 B_2 which corresponds to the part of A_3 B_3 occupying the pupil, went to every point in the lens L L. The whole lens L L would then appear to the eye E to have a brilliancy nearly equal to that of the flame. In this case, however, it would not be practicable to illuminate so large an area with the maximum intensity as we might do with the same lens by Helmholtz's method; because the eye E would require to be further from the lens, and the angle subtended by the lens, which regulates the size of the illuminated area of the fundus oculi, would be smaller. The reflector too would require to be larger than would be necessary if Helmholtz's plan were followed. In both cases it might be possible to illuminate a somewhat larger area, but with a less intensity, by bringing the patient's eye a little nearer to the lens. It will be observed that in fig. 4, the circumstances are not the most favourable, either in respect of intensity of illumination, or extent of area illuminated, which might be imagined in connection with the method of illumination represented in it; because something has been sacrificed to convenience in delineation and description. The truth is, that with a flame of ordinary size, a concave reflector of about 6 inches focal distance, and $1\frac{1}{2}$ inch diameter, and a biconvex lens of from 2 to 3 inches focal distance and corresponding aperture, we can generally illuminate a sufficiently large area with sufficient brilliancy. It is not necessary that we should attain the maximum in these respects with theoretical accuracy, and it is impossible in ordinary practice; but the observer will find that he can make an approximation to it by altering the distance between the flame and the reflector, and that between the lens and the patient's eye, taking care that his own eye is at the proper distance from the lens.

An opaque concave reflector has a great advantage over such an instrument as that of Helmholtz when the indirect method of examination is employed. The light which then falls upon a given point on the patient's fundus oculi, comes from a large area of the reflecting surface, and the loss due to the hole in the reflector is comparatively small. Hence a greater apparent brilliancy of *all* parts of the visible area can be obtained *in practice* by means of the inverted image.

After the first invention of the ophthalmoscope by Helmholtz, the introduction of oncave reflectors and the indirect method of examination by Ruete was the greatest step in the history of the instrument. The former seems to have been the first to point out and demonstrate the optical conditions necessary to be fulfilled in order to the distinct perception of the human fundus oculi in the normal state. The possibility of seeing the reflected light had been already practically demonstrated, and the means of attaining this pointed out by Cumming and Brücke.

Various additions, such as micrometers and the camera lucida, have been adapted to the more complicated forms of the instrument, such as the ophthalmoscope of Epkens and Donders, and that of Liebreich, with the view of enabling the observer to take measurements and drawings of objects upon the retina. The practical working of such instruments requires a good deal of skill and experience on the part of the observer; and, as already stated, they are not so well adapted for medical practice as the simpler ones. Jäger's ophthalmoscope has the advantage of enabling one to make use of an opaque concave reflector, or glass plates, after the manner of Helmholtz, at pleasure; but it is rather a bulky instrument to carry about. A great number of very portable small instruments have been constructed, consisting for the most part of a concave reflector furnished with a handle, to which is attached a small arm to carry the lens used as an eye-piece, and accompanied by a large 2½ inch biconvex lens, and several smaller concave lenses of, say, 10, 8, 6, and 4 inches focus, with a biconvex of 6 or 8 inches focus made to fit the arm.

Part V.—INTERPRETATION OF PHENOMENA OBSERVED.

In making ophthalmoscopic examinations, the observer is often apt to be misled by optical illusions in drawing conclusions with respect to the magnitude, colour, position, and stability of the objects which he sees; and to err in his diagnosis in consequence of preconceived opinions with regard to the appearances which are consistent with a normal state of the eye, and in consequence of erroneous impressions about the causes which combine to produce varieties in the appearances. A knowledge of the varieties which may be met with in different eyes, and of their rationale, is of such practical importance and so intimately connected with our subject, that I may be allowed to make a few remarks upon the more important phenomena to be met with in health and disease, and upon some of the illusions by which the observer is most likely to be misled.

The fundus of a normal eye, when examined ophthalmoscopically, presents a pretty uniform orange or pinkish colour; and, when the observer's eye is accurately adjusted for it, a finely granulated appearance, except at the place where the optic nerve enters, which will occupy the centre of the observer's field of vision when his axis of vision is directed somewhat downwards and inwards at an angle of 20° to 25° to that of the patient. The general hue of this spot is yellowish or greyish white, but it is not quite uniform in shade; and its form is nearly circular, but it is occasionally somewhat longer in its vertical than in its horizontal diameter, and irregular in its contour even in sound eyes.

The retinal vessels are seen to rise out of the entrance of the optic nerve, near its centre; and they can be traced from this over a great part of the fundus oculi. Before leaving the surface of the optic disk they generally divide into two principal arterial, and two principal venous trunks; an artery and vein going upwards and outwards, and another pair downwards and outwards, and arching round the site of the macula lutea, which is free from vessels. The venous trunk generally divides into its two principal branches in the substance of the nerve, near the surface; the artery often remains single for some little way after it has come to the surface; but there are considerable varieties in the distribution of these vessels. The arteries may be distinguished from the veins by their smaller calibre, lighter colour, and more strongly marked double contour, which arises from the greater reflecting power of their coats.

By slightly altering the focal adjustment of his eye, the observer may often see the observed fundus oculi streaked something like the skin of a tiger. This arises from the perception of the larger choroidal vessels, and their interspaces through the superficial layer of pigment cells; and the appearance is most easily seen towards the circumferential parts of the fundus oculi, and in the eyes of persons of fair complexion.

When we proceed to investigate the rationale of these appearances, we are at once struck with the difference between the dark brown colour which is presented by the fundus of a dissected eye seen by ordinary day-light, and the clear orange tint which it assumes when illuminated by the ophthalmoscope. This is, no doubt, to be explained partly by the intensity of the light concentrated upon it, partly by the absence of contrast with other objects equally well illuminated, and partly by the presence of red blood circulating in it. If we trace the course of the light sent from the ophthalmoscope after it has passed through the refracting media, it must be observed that it first meets with the retina, which, being smooth and transparent, reflects but little light either regularly or irregularly when the light falls nearly perpendicularly on its surface, as it must of necessity do. It next reaches the layer of hexagonal pigment cells covering the choroid internally, when a considerable proportion is absorbed, some is transmitted, and a good deal seems to be reflected.* The transmitted light arrives at the choroidal vessels in the next place, and some is reflected, some transmitted, and some absorbed; the pigment in the interstices between them will, if strongly developed, absorb most of the light which falls upon it; but some may be transmitted through both it and the ves-

* E. Jäger regards this layer of hexagonal cells as the principal reflector in the normal state of the fundus oculi. This opinion seems to be mainly grounded on the fact that, in certain cases where the superficial layer has been partially destroyed, the fundus oculi presents a lighter colour than it does in parts denuded of this layer; and he states that its pigment appears reddish or orange by strongly concentrated light. Others, however, explain the matter differently. Ergebnisse der Untersuchung des Menschlichen Auges: Wien, 1855.

sels to the sclerotic which has a great reflecting power. The light returning from these more deeply seated parts suffers loss from absorption in passing again through the more superficial ones; and it is also dispersed by them in such a way that it rather tends to affect the colour of the latter, and the apparent brilliancy of the image which we see, than to give us a definite perception of the form and colour of the objects from which it is reflected. The less strongly developed the superficial pigment is, the less absorption and dispersion will take place.

In various diseased conditions, the layer of the hexagonal cells becomes destroyed or atrophied, and in this case we may see the choroidal vessels very well, with their interstices filled with dark pigment; but this may sometimes be observed in the case of persons with well-developed interstitial pigment and little development of pigment in the superficial layer; such cases, however, are rare. Again, both superficial and deep-seated pigment may be destroyed by disease, and then we see the choroidal vessels against the white ground of the sclerotic; but something similar may be seen in the eye of an albino, or a person of very fair complexion. Finally, the choroid may be atrophied in its whole thickness at particular parts, as in staphyloma posterius, and we then see nothing but the white sclerotic; but this may be simulated by white patches, the result of inflammatory exudation, fatty deposits in the retina, &c.

In all such cases, we must pay particular regard to the complexion of the patient, and the history of his case. The seat of the abnormal appearance may often be detected by observing whether the retinal vessels pass in front of or behind the white patches observed; and we may generally distinguish the results of atrophy, or destruction of pigment, from those of original conformation, by the irregularity of the distribution of pigment in the former case, and from those due to exudations, &c., by their not being so sharply defined in general.

Masses of dark pigmentary matter are sometimes observed on the fundus oculi. They may or may not be of pathological importance; and a sickle-shaped deposition of this kind is common at the margin of the papilla optica.

The transparency of the retina may be impaired, and its reflecting power increased in consequence of inflammatory disease. The effect of this is to give a hazy indistinct appearance to the fundus oculi. The observer must be on his guard against confounding this with an indistinctness due to improper focal adjustment of his own eye, or to turbidity of the media, or with the faint greyish colour which the fundus presents occasionally in very dark subjects—a phenomenon which appears to me to be explicable upon principles referred to in Part I. When the retina is separated from the choroid by serous exudation, some parts may appear bluish grey, or white, and others almost black, according as the light regularly reflected from their surfaces enters the eye of the observer or not. A good deal also depends upon the colour of the subjacent fluid, and upon contrast with parts of the fundus which present the usual appearance.

The papilla has a red appearance in various diseases, owing to increased vascularity of its surface; but its colour varies considerably in the normal state, often resembling grey cerebral substance, and it is sometimes pinkish. Some parts of it appear to reflect more light than others—a fact which is attributable to our being often able to see back to the lamina cribrosa. The more brilliant parts correspond to those in which fibrous tissue predominates, and the darker ones to the transparent substance of the nerve-tubes along the axes of which we look.

The papilla sometimes appears abnormally large and vascular, viz., in cases of staphyloma posterius at a certain stage where the sclerotic appears around the optic disk in consequence of atrophy of the choroid; and small retinal vessels, which cannot be distinguished on the orange ground in a normal eye, come into view. Eyes affected with this disease are more or less myopic; and the optic disk proper appears hardly so white as the surrounding sclerotic denuded of the choroid.

The choroid hardly comes to the margin of the place of entrance of the optic nerve, even in a normal eye, and on this account the nerve substance may be much atrophied, according to Liebreich, without an apparent diminution in the diameter of the disk.

The papilla optica, which does not really present the form of a globular elevation during life, sometimes appears as if it did so when it is observed by means of the ophthalmoscope. One cause of this has been pointed out by Liebreich, who has drawn attention to the fact that the distribution of dark and light coloured parts resembles that in a representation of a sphere well executed on a plane surface.* When the optic nerve is cupped or excavated, as in glaucoma, this appearance comes out more strikingly, especially when the indirect method of examination is employed, because we are then subject to another optical illusion depending upon the reversal of the image, and similar to that in consequence of which the inverted image of an intaglio produced by a biconvex lens, resembles a cameo; the shadow thrown by the margin of the cup or excavation appearing to be on the side opposite to that from which the light comes to it instead of on the same side.† This illusion is, for obvious reasons, most striking when the image of the disk is near to one side or other of the observer's field of vision.

In cases where the optic nerve is deeply excavated, the bottom

* Gräfe's Archiv, Bd. i., Abt. ii.

† See "A Fragment on Glaucoma," by Dr. Mackenzie, in No. xi. of the London Ophthalmic Hospital Reports.

of the cup appears to be of a greenish colour, while its margin (corresponding to the part of the sclerotic immediately surrounding the nerve, and not covered by choroid) has a yellowish white colour, and a brilliant aspect at certain parts from its reflecting the light like the rim of a cup. The retinal vessels may be seen passing over this to reappear indistinctly at the bottom of the cup, and they may seem more or less dislocated as they do so, according to the position of the patient's eye with respect to the observer, and according to the position in which the biconvex lens is held, if one is made use of.*

When we perceive opaque bodies situated in the media, by eans of light coming from the fundus oculi, they will appear lack, whatever their real colour may be; thus, opacities in the ens, though they may appear grey, or even white, under ordinary ircumstances and contrasted with a black pupil, appear like lack spots or streaks upon the illuminated fundus. We may, no oubt, see light reflected from the fundus oculi, and light reflected om opaque bodies in the media at the same time, and contrast ill then determine in a great measure the appearance presented y the latter. Supposing an opacity in the lens to have a power reflecting light falling almost perpendicularly upon it equal to at of the fundus oculi, the former would appear dark in comarison with the latter, if the illuminated area of the fundus were maller than the area of the pupil; because the fundus would in at case be better illuminated than the opacity, and the observer ould in general see each with nearly its proper brilliancy, ovided the pupil of the observed eye were somewhat larger an his own.

In all cases in which the observer seeks to draw conclusions om the colour of objects seen within the eye, he must remember make allowance for the quality of the light by which they are uminated, and which reaches his own eye after undergoing rious modifications consequent upon its reflection from, and ansmission through other bodies, besides those which it renders stinctly visible.

It will be found that objects seen by means of the ophthalmoope generally present a lighter shade of colour than they do en seen by ordinary daylight, especially if the direct method is aployed.

The principles upon which we may determine the state of focal justment of the observed eye have been already discussed. The portance of the ophthalmoscope used for this purpose in military d medico-legal practice, has been pointed out by Professor E. ger of Vienna.† He refers to a circumstance, which may

* The reader will find observations on this subject by Mr. Streatfield. hthalmic Hospital Reports, No. xi.

† Der Augenspiegel als Optometer, österr. Zeitschrift für practische ilkunde, March, 1856.

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rather embarrass the observer in examining hyperpresbyopic eyes in the direct manner, viz., that in extreme cases the apparent magnitude of the image of an object, such as the papilla, may not exceed a third or a fifth part of what it appears in a normal eye. A much larger area is then seen, and this circumstance may add to the difficulty of illuminating hyperpresbyopic eyes, referred to in Part II. The illumination may or may not be fainter than it is in a normal eye, according to the mode in which it is accomplished, and according to the cause of the hyperpresbyopia, whether dependent on absence of the lens, &c., or on shortening of the axis of the eye; but the area illuminated will always appear smaller than one of equal dimensions in a normal eye, and it will seldom occupy the whole of the observer's field of vision.

Apparent motions of objects situated in different planes within the eye, are often very difficult to distinguish from real ones. They may depend on motions of the eye observed, or on motions of the observer, or the biconvex lens held in his hand. The apparent changes in the position of objects caused in this way may be regarded as an exaggeration of those observed in looking at objects from different points of view under ordinary circumstances; except that in the direct mode of examination, it is the most distant objects which appear to move most rapidly, instead of the nearer ones, as is always observed in nature, and generally in the inverted image.

ERRATA, &c.

Page 6, *et passim*, for "Helmholz" read "Helmholtz."

Page 21, formula (V.), for "— (F + r)," in the denominator, read "f — (F + r)."

Page 29, line 33, for "lost by transmission or absorption," read "lost by transmission, absorption, or irregular reflection."

Page 32, line 32-37. The limit in this case is the angle subtended at the optical centre of the eye by the image of the lens produced by the reflector.

Page 53, line 37, and page 54, line 2. In the examination of hyperpresbyopic eyes by the direct method, we may employ a convex lens, as a concave one is employed in examining myopic eyes. If this convex lens were held close before the patient's eye, it would be theoretically possible to see a virtual erect image of the fundus as much magnified as a real inverted one could appear with equal brilliancy, provided the patient's pupil were not larger than the observer's.

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