MODERN OPTICAL INSTRUMENTS

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AND THEIR CONSTRUCTION

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BY

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PREFACE

The main object of the author in compiling the following book has been to place before the reader a descriptive outline of a few of what may safely be termed the more popular optical instruments in use. Taking the human eye as the most important, most instructive, and certainly the most valuable optical instrument known to science, its construction and properties are first of all dealt with in detail, and are followed by an explanation of the defects and aberrations to which our eyes are not infrequently subject.

It is believed that the succeeding chapters, which deal with the theory and practice of ophthalmoscopic examination, together with the fully-illustrated remarks on spectacles and their various forms, and of the principles governing their use and selection, will be appreciated as an endeavour to constitute this part of the work of direct utility and information.

Although subsidiary to the principal theme of the work —Ophthalmoscopy—the chapters on the Stereoscope, the Optical Lantern, the Spectroscope, and Stercoscopic Projection will, it is hoped, be welcome to the reader as affording him an introduction to the study of several branches of optics, as interesting as they assuredly are full of possibilities in the way of practical application.

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MODERN OPTICAL INSTRUMENTS AND THEIR CONSTRUCTION

CHAPTER I

THE EYE AS AN OPTICAL INSTRUMENT

THE strides made in the construction of optical instruments has led me to compile the following chapters relating to the subject, which will, no doubt, prove interesting to many. I shall endeavour to explain the use of the different instruments for their especial purposes, and also their construction, and the object of each part; but, before starting, it would be as well to examine Nature's optical instrument, and having seen the construction of that, we shall then see how many of the optical instruments are approximately the same in their construction.

DESCRIPTION OF THE HUMAN EYE.—The eye, Fig. 1, as an optical instrument, consists essentially of a series of refracting media bounded by curved surfaces, and a network of small nerve-fibres, forming part of the optic nerve. A pencil of light incident upon the eye is refracted at the curved surfaces, and brought to a focus on the network of nerve-fibres, and the impression carried to the brain along the optic nerve.

The human eye is nearly spherical in shape, except in front, where it assumes a shorter curve, and protrudes. It is invested in a tough coat, which, except in the part which protrudes, is opaque and white; this is called the

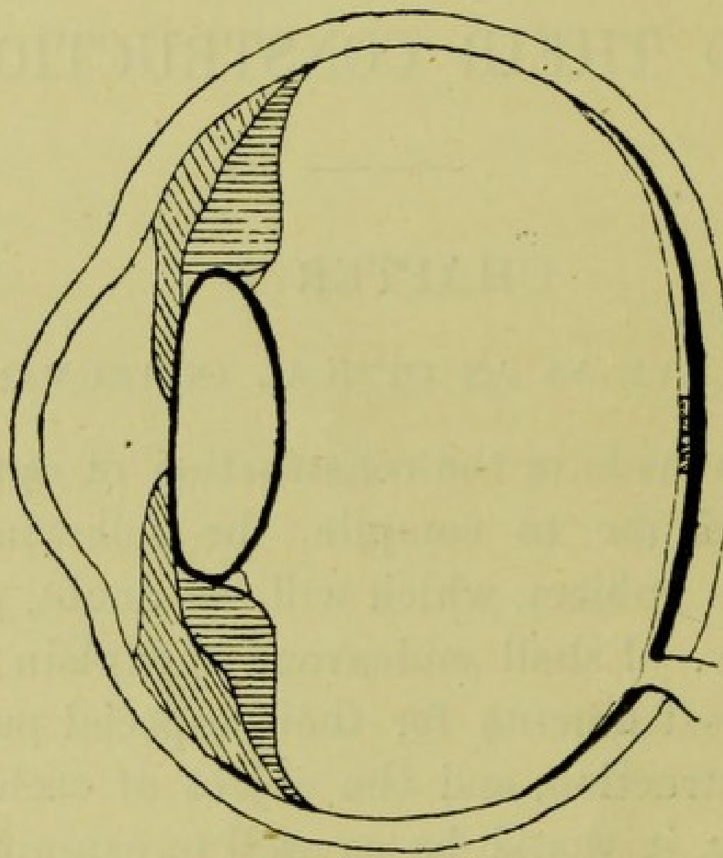


FIG. 1.

sclerotic. This is commonly termed the white of the eye. The part which protrudes is covered with an extremely strong and thick transparent membrane, which is called the cornea. The eyeball has also two other linings: just within the sclerotic is a thin membrane called the choroid, and within that there is another thin lining called the retina. The interior of the choroid is covered with a black pigment, which gives it a velvety appearance. Its use is to absorb rays of light which have passed through the retina, and prevent them from being reflected back on it, and interfere with the images there formed.

THE IRIS.—The anterior portion of the choroid, separating from the sclerotic, is thickened and forms the iris, which is a contractible curtain perforated by an aperture in the centre, called the pupil. The outer edge of the iris is fixed, but the centre may be contracted by a strong muscular band running round it, which allows the size of the pupil to be changed. The use of the iris is to regulate the quantity of light which falls on the sensitive parts of the eye. In strong light the pupil contracts automatically, and in feeble light expands. The anterior surface of the iris is differently coloured in different persons, and the posterior surface is covered with black pigment, which absorbs any light which may fall upon it, due to internal reflection, etc. Before separating from the sclerotic the choroid splits into two layers: the anterior goes to form the iris, while the posterior is gathered into a plaited curtain, which surrounds the outer edge of the crystalline lens, like a collar. These plaits are seventy-two in number, and are called the ciliary processes. Beneath this dark collar, and therefore in contact with the sclerotic, is a muscular collar with radiating fibres, called the ciliary muscle.

THE RETINA.—The retina is a delicate, semi-transparent membrane, resulting from the spreading out of the optic nerve, and is composed of the terminal fibres of this nerve and nerve-cells, and covers the whole interior of the ball as far as the ciliary collar. Exactly in the centre of the retina is a yellowish, round, elevated spot, about $\frac{1}{20}$ inch in diameter, having a minute indentation called the fovea centralis at its summit. This is the point of distinct vision, and the fovea centralis is the most sensitive part of the retina. About $\frac{1}{10}$ inch on the inner side of the yellow spot is the point at which the optic nerve spreads out its fibres to form the retina: this is the only spot on the retina which is not sensitive to light, and is therefore called the blind spot.

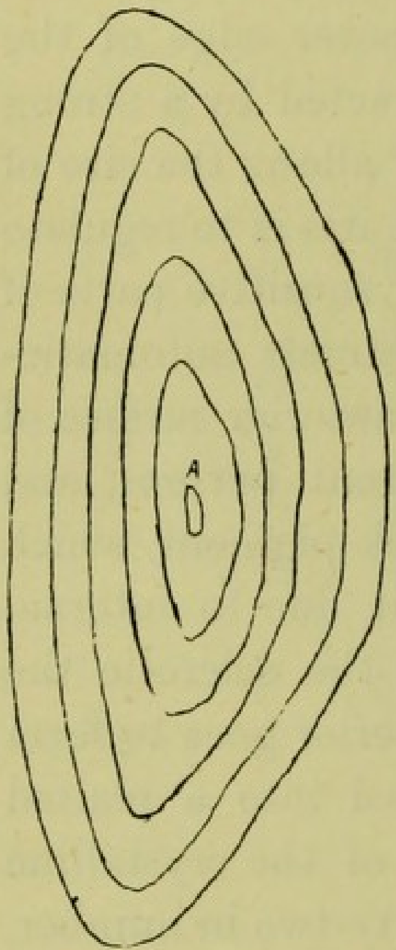


FIG. 2.

THE CRYSTALLINE LENS.—Within the eye, just behind the iris, is suspended a soft transparent body, called the crystalline lens, of the form of a double convex lens, whose anterior surface is much less curved than the posterior. The crystalline lens is contained in a transparent capsule, and is kept in its place by the ciliary processes. It is composed of successive layers, Fig. 2, whose refractive indices increase towards the centre, its solid nucleus, A, refracting light most powerfully. It is easy to see that the action of the lens is more powerful than if it were composed of homogeneous substance having the same refractive index as the nucleus. For it may be regarded as the combination of a double convex lens *c*, Fig. 3, with two concave lenses, *a* and *b*. These concave lenses will neutralize the effect of the lens *c* to a certain extent, but not so much as if their refractive indices were as high as that of *c*. The focal length may be found by experiment; its shape being known, its total refractive index may be found—that is, the refracting index which the lens would possess if it were homogeneous. The increase of refracting power from the outer portions to the inner portions of the lens serves partly to correct the aberration by increasing the convergence of the central rays more than that of the extreme rays of the pencil.

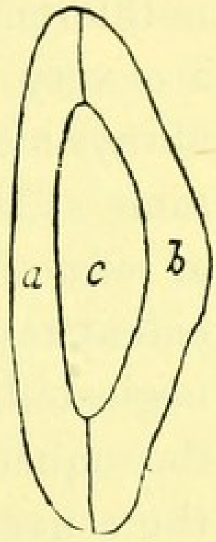


Fig. 3.

The space between the cornea and the crystalline lens is filled with transparent fluid resembling water, and is termed aqueous humour. The space between the crystalline lens and the retina is filled with another transparent fluid, somewhat more viscous than the former, and therefore called vitreous humour. These two humours are contained in delicate capsules like the crystalline lens. In these refractive indices the aqueous and vitreous humours differ very little from water, while the total refractive index of the crystalline lens is a little greater than that of water.

Refraction of the Eye.—To determine the manner in which a pencil of light incident on the eye is refracted by it, we must know the refractive indices of the different media of which the eye is composed, and the forms and positions of the bounding surfaces. The anterior surface of the cornea is very nearly that of a segment of an ellipsoid of revolution, the axis of revolution being the major axis. The form of the posterior surface is but indifferently known; but the two surfaces of the cornea are very nearly parallel, and as the anterior surface is always moistened with water, whose refractive index is the same as the aqueous humour, the cornea acts like a plate of refracting medium, and produces no deviation on an incident ray. The cornea itself may, therefore, be entirely neglected, and we may suppose for optical purposes that the aqueous humour extended to the anterior surface of the convex.

There are, therefore, three surfaces at which refraction takes place: the first surface of the convex and the two surfaces of the crystalline lens. The centres of these curves are nearly in a straight line, called the optic axis. For rays whose deviations from the axis are not large, the surfaces may be supposed to coincide with the spheres of curvature at their respective vertices. Gauss's theory of refraction at any number of spherical surfaces whose centres lie along an axis is therefore applicable to this case, and the positions of the focal points, the principal points, and the nodal points may be found by calculation as soon as the radii of curvature, the positions of the refracting surfaces, and the indices of refraction of the media are known.

Listing has given the following numbers as representing very closely the constants of an average eye. In reckoning refractive indices the refracting index of the air is taken to be unity. The radii of curvature of the bounding surfaces have the following values:—1. The anterior surface of cornea 8 millimètres. 2. The anterior surface of the lens 10 millimètres. 3. The posterior surface of the lens 6 millimètres. The distances between the refracting surfaces from 1 to 2, 4 millimètres; from 2 to 3 (thickness of the lens), 4 millimètres; from 3 to the retina, 13 millimètres. The indices of refraction are:—1. For the aqueous humour, $\frac{103}{77}$. 2. For the lens (total), $\frac{16}{11}$. 3. For the vitreous humour, $\frac{103}{77}$. From these data he calculates the positions of the cardinal points according to Gauss's theory, and finds that the two principal points lie very close together, as do also the two nodal points, so that without introducing much error, we may regard them as coinciding in each case. The single principal point lies 2·3448 millimètres behind the cornea, and the nodal point ·4764 millimètre in front of the second surface of the lens.

Such an eye is exactly equivalent to a single-refracting spherical surface, whose vortex is at the principal point and centre of the nodal points, the refractive index being $\frac{103}{77}$, as before. A point and its image on the retina will lie on a line passing through the nodal points, and therefore if we wish to find in what direction lies a point whose image is in a given position on the retina, we have only to join the image to the nodal point, and produce the line outwards. When the eye is passive, it is clear that only the points which lie in a single surface will have images falling exactly on the retina. The form of this surface and its position may be determined from the optical constants of the eye. Any object lying on this surface will have an image on the retina similar to the original figure, but inverted, the lines joining corresponding points of the object and the image, all passing through the nodal point. But if a point does not lie on this surface, its image will not be on the retina, but in front of or behind it. In both cases the retina cuts the pencil of refracted rays, not in a single point, but in a circle of diffused light.

Hence it follows that an immovable eye can only see distinctly objects lying in one surface, and if we consider only rays of light making small angles with the axis of the eye, this surface may be considered plane. All objects, or portions of objects, not lying in this plane give indistinct images, in which circles of diffusion correspond to luminous points of the object. Experience teaches us, however, that an eye is capable of seeing distinctly at almost any distance; there must, therefore, exist an arrangement for altering the eye, and adapting it for seeing different distances at will.

ACCOMMODATION.—The changes which occur as the result of this arrangement are included under the term accommodation. It is not known with absolute certainty for what distance an eye is adjusted when it is not actively accommodated; but it is almost universally supposed that a normal eye, when passive, is adjusted for objects at an infinite distance, so that the second focal point of the eye at rest is on the retina. It has been found by experiment that accommodation is effected by change of form in the refracting surfaces of the eye. When the eye is accommodated for near objects, the anterior surface of the crystalline lens becomes more strongly curved, and approaches nearer the cornea. This is especially the case with the part not covered by the iris, which arches forward through the pupil. It has been seen that when the eye is at rest in any position, and accommodated for an object, there is one point, the fovea centralis, where the vision is distinct, but that the vision is distinct only for a small area about this spot. But the eye is usually in very rapid motion, and in an incredibly short space of time brings the various points of an object into distinct view.

We are thus enabled to form a clear conception of a considerably extended surface. This is aided also by the duration of the impression produced by a light. It has been found by experiment that this duration depends on the character of the light. For strong lights, Helmholtz gives one twenty-fourth of a second, and for weak lights one-tenth of a second, as the duration of the impression; Lissajous and others assign about one-thirtieth of a second as the lowest limit of the duration. If a spot on the retina be stimulated by a regular periodic light whose period is sufficiently short, there will arise a continuous impression, which in intensity is equal to what would be produced were the whole incident light of any period uniformly distributed over the whole period.

Binocular Vision.—The retinæ of both our eyes receive impressions. When we look at any external object, and in certain positions of our eyes, we see two images, arising from the two retinæ, while in other positions we only see one image. To each point to one retina there is a corresponding point on the other, and when the images of an external point, formed by the two eyes, fall on corresponding points of the two retinæ, the point is seen single; but in other cases it is seen double. The points on the retina of an eye may be referred to two meridians formed on the retina by two planes through the axis of the eye. When the eye is directed forwards in a horizontal position, the points on the horizon have images lying on a meridian, which we may call the retinal horizon. Similarly certain lines appear vertical to an eye; the retinal image of these vertical lines is a meridian, which we may call the apparently vertical meridian.

By experiment Helmholtz concludes that the retinal horizon is actually horizontal for both eyes; but that the apparently vertical meridians are not quite perpendicular to the retinal horizon, they diverge outwards at their upper extremity. The inclination of each of these meridians to the real vertical is the same, and they include between them an angle varying from 2° 21′ to 2° 33′. Helmholtz also finds that in normal eyes the points of direct vision, as well as the retinal horizons and apparent verticals in the two eyes, correspond; and, further, that corresponding points are equally distant from each retinal horizon, and from each apparently vertical meridian.

Our most accurate estimate of the distances of visible objects depends upon us having two eyes. As we fix our gaze successively upon points at different distances, we have to change the convergence of the axis of the two eyes, and from the degree of convergence to these axes, when we look at any point we form an estimate of the distance of the point. Our idea of solidity also depends upon vision with two eyes. The views presented to the two eyes are slightly different, because the eyes have slightly different positions, and it is by the blending of the two impressions received upon the two retinæ that we receive the idea of solidity.

This can be well shown by the aid of the stereoscope. This instrument was invented by Wheatstone for the purpose of combining two photographic pictures, one of which is presented to each eye. These pictures are not exactly alike, but are taken by a camera, with two lenses placed a small distance apart, so that they represent two different views, such as might be presented to two eyes observing the scene. By means of mirrors or prisms the pictures are seen superimposed, and the impression produced on the mind by these superimposed views is exactly the same as if we were looking at the real scene, each object appearing in relief, as in nature. For a perfect stereoscopic representation the points at an infinite distance must fall on corresponding points of the two retinæ, where the axes of the eyes are parallel. If the pictures are brought nearer to each other in the same plane than in the positions thus determined, the impression is exactly that of a relief picture.

CHAPTER II

PROPERTIES AND ABERRATIONS OF LENSES

THE instruments that have been constructed for the eyes are divided into two classes: the first for the correction of aberrations of the eye itself; and, secondly, the class for the detection and examination of those aberrations. The first are called spectacles, and the second ophthalmoscopes. If we first thoroughly examine the elements which constitute a spectacle-lens (the most common optical instrument), it will be comparatively easy to understand how the aberrations of the eyes may be almost counteracted by their judicious use.

REFRACTION.—Pencils of light are deviated or refracted when they pass from one transparent medium into another of different density. If the deviation in passing from vacuum into air be represented by the number 1 that for crown glass is 1·5, and for rock crystal 1·66. Such a number is the refractive index of the substance. Every ray is refracted except those which fall perpendicular to the surface, as the ray *a a* in Fig. 4. In passing from a less into a higher refracting medium, the deviation is always towards the perpendicular of the refracting surface; in passing from a higher into a lower refracting medium, it is always and to the same extent away from the perpendicular (see ray *b b*, Fig. 4, and the angles *x* and

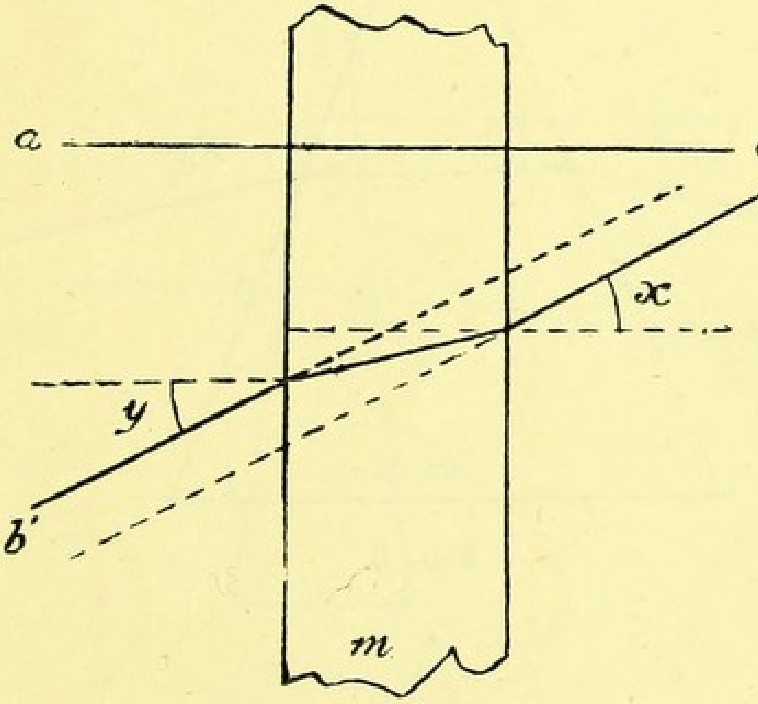


Fig. 4.

y). Hence, if the sides of the medium be parallel, as in Fig. 4, the rays on emerging are restored to their original direction, but in a different path, and the thinner the medium, the less the deviation from their path will be.

If the medium be formed as a prism, the sides of *m*, Fig. 5, form an angle, the angles of incidence and emergence *x* and *y* still being equal, *b′* must also form an angle with *b*. The angle *a* is the refracting angle or edge of the prism; the opposite side is the base. As seen in Fig. 5, the light is always deviated towards the base. The deviation shown by the angle *d* is equal to about half the refracting angle *a* if the prism be of crown glass. The relative direction of the rays is not changed by a prism, and if parallel or divergent before incidence, they are

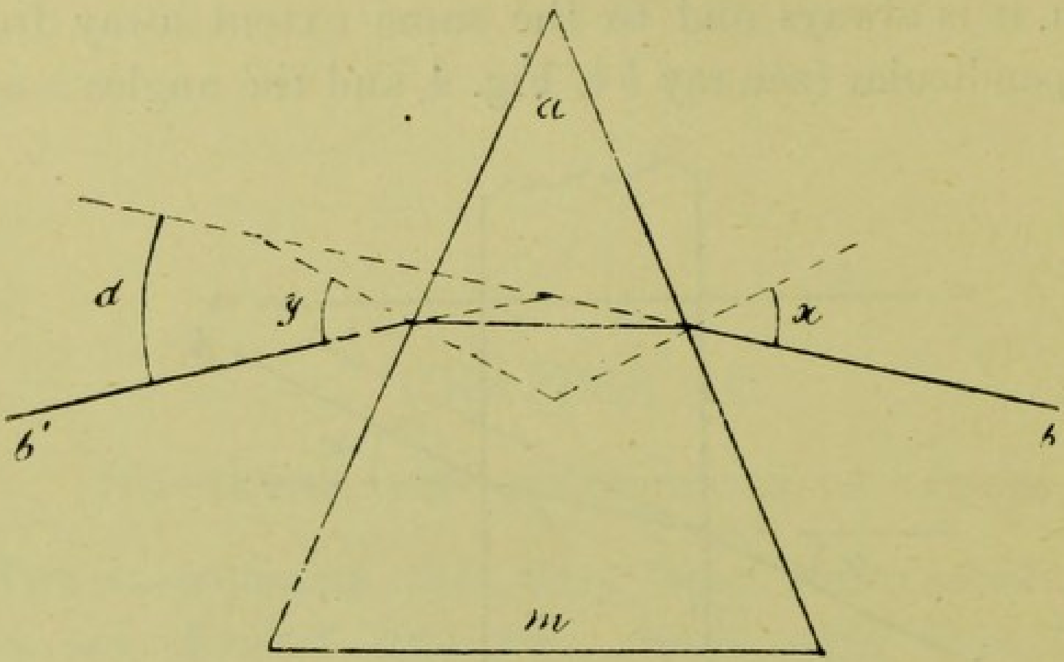


Fig. 5.

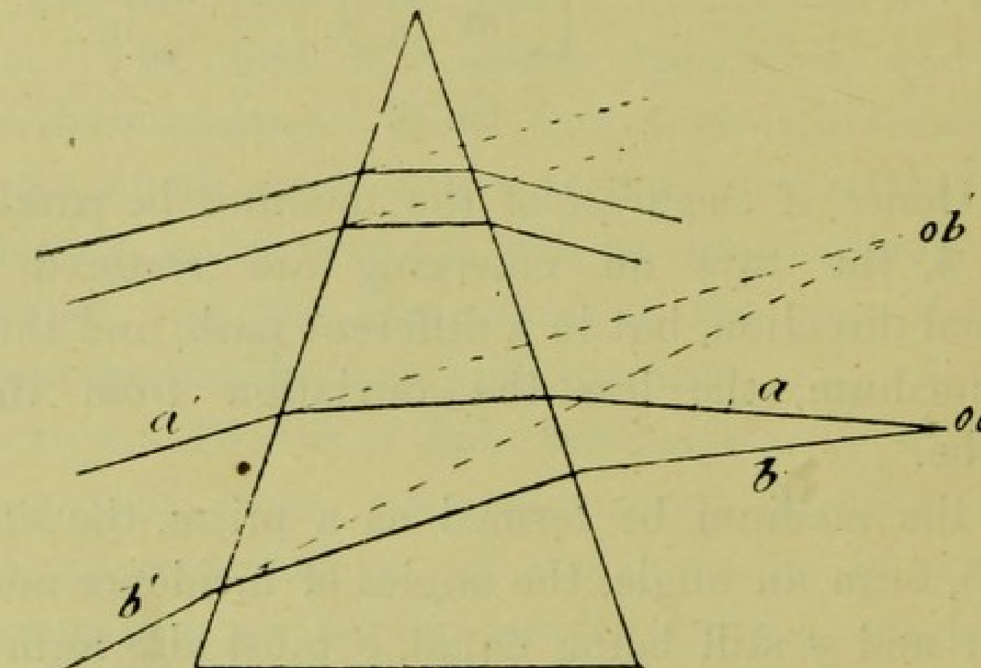


Fig. 6.

parallel or similarly divergent after emergence, as shown in Fig. 6. An object seems to lie in the direction which the rays have as they enter the eye; *o b* in Fig. 6, seen by the eye at a' or b', seems to be at $o\ b'$, where it would be if the rays $a'\ b'$ had not deviated. With very thin prisms the deviation a and b (Fig. 7) remains the same for varying

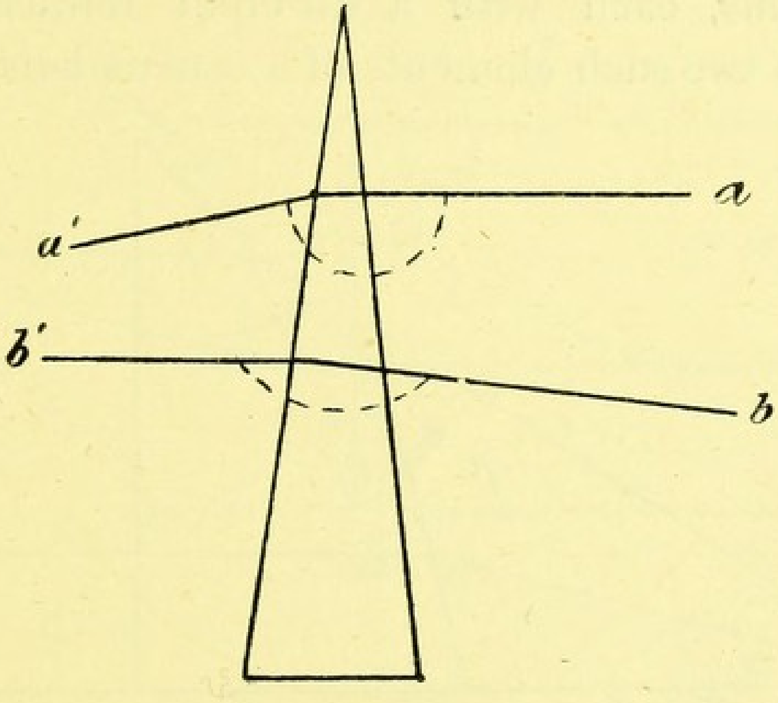


FIG. 7.

angles of incidence. For thin lenses, this is expressed by saying that the angle d (Fig. 8) is the same for the rays a

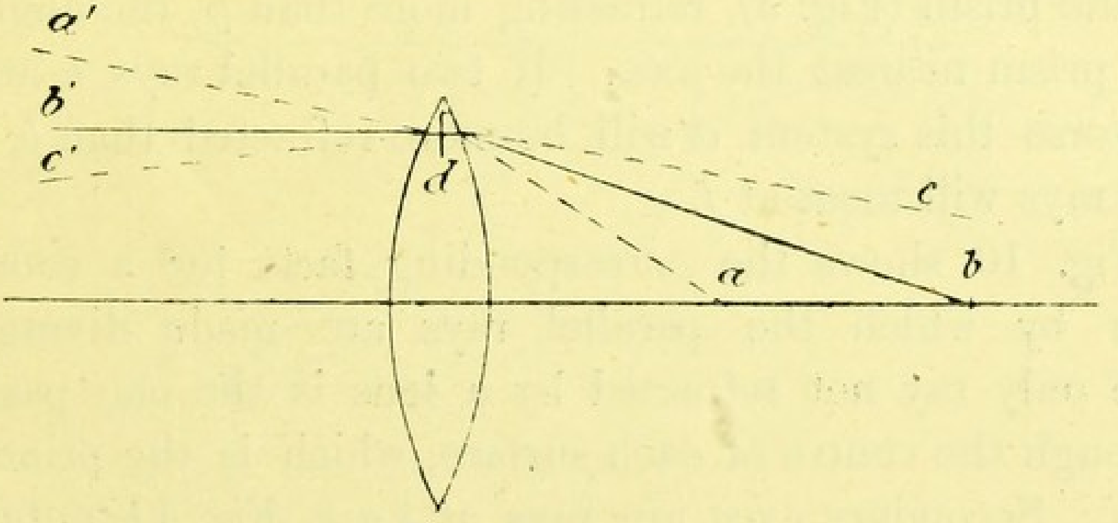


FIG. 8.

a', $b\ b'$, $c\ c'$, incident at different angles, but at the same distance from the axis.

An ordinary lens is a segment of a sphere, or of two spheres whose centres are joined by the axis of the lens. We can regard a lens as formed of an infinite number of minute prisms, each with a different refracting angle. Fig. 9 shows two such elements of a convex lens, the angle

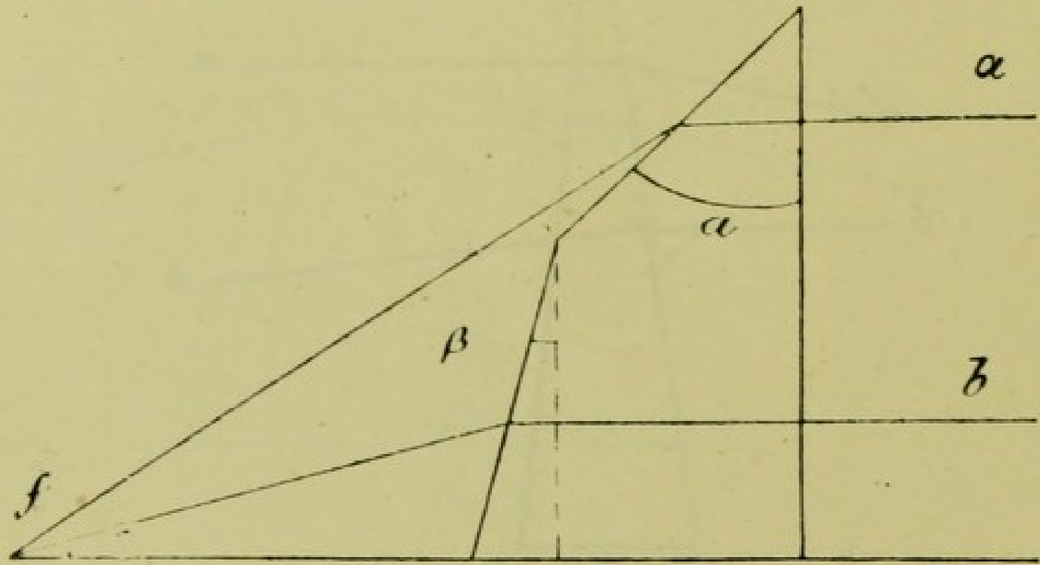


FIG. 9.

a of the prism at the edge of the lens being larger, and therefore, in accordance with the statement of the action of the prism (Fig. 5), refracting more than β, the angle of the prism nearest the axis. If two parallel rays, a and b, traverse this system, a will be more refracted than b, and the rays will meet at f.

Fig. 10 shows the corresponding facts for a concave lens by which the parallel rays are made divergent. The only ray not refracted by a lens is the one passing through the centre of each surface, which is the principal axis. Secondary axes are rays as *s a x*, Fig. 11, entering and emerging at points on the lens parallel to each other, and hence not altered in direction. All rays which pass through the central point of a lens are secondary axes, except the principal axis. Fig. 12 shows spherical aberration, which increases with the curvature of the

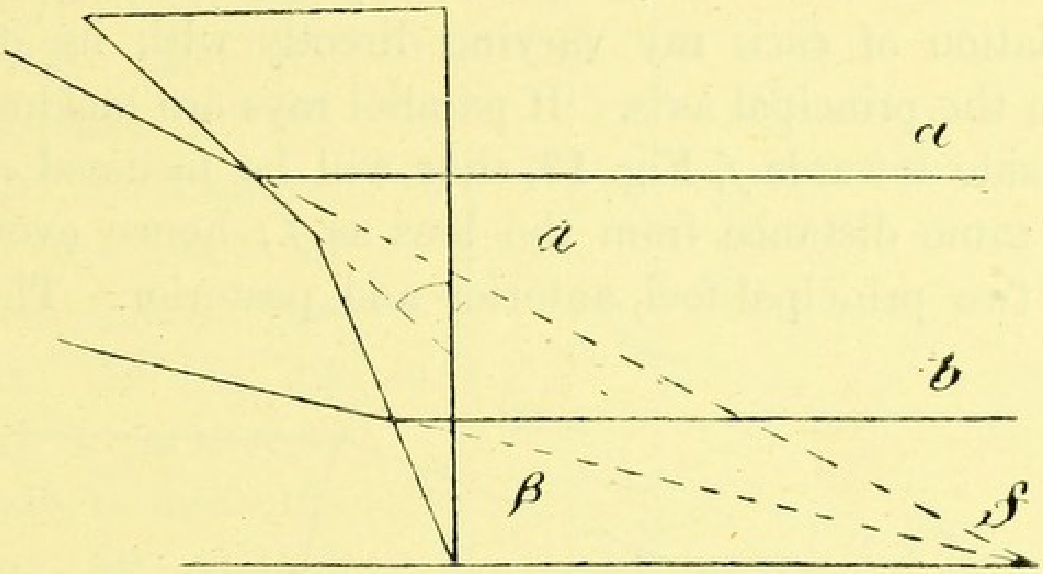


Fig. 10.

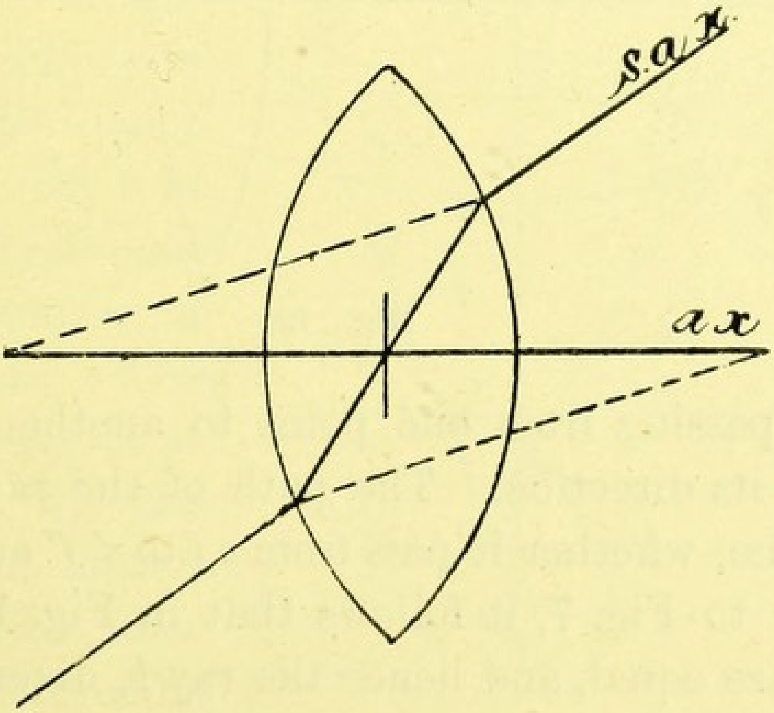


Fig. 11.

lens; but if stopped off, which is done in the eye by the iris, is not so apparent at the same time with a corresponding loss of light.

The principal focus of a lens, *f*, Fig. 13, is the point where the rays *a a*, that were parallel before they entered the lens, meet, after they have passed through it, the deviation of each ray varying directly with its distance from the principal axis. If parallel rays are incident from the side towards *f*, Fig. 13, they will be focussed at f' at the same distance from the lens as *f*; hence every lens has two principal foci, anterior and posterior. The path

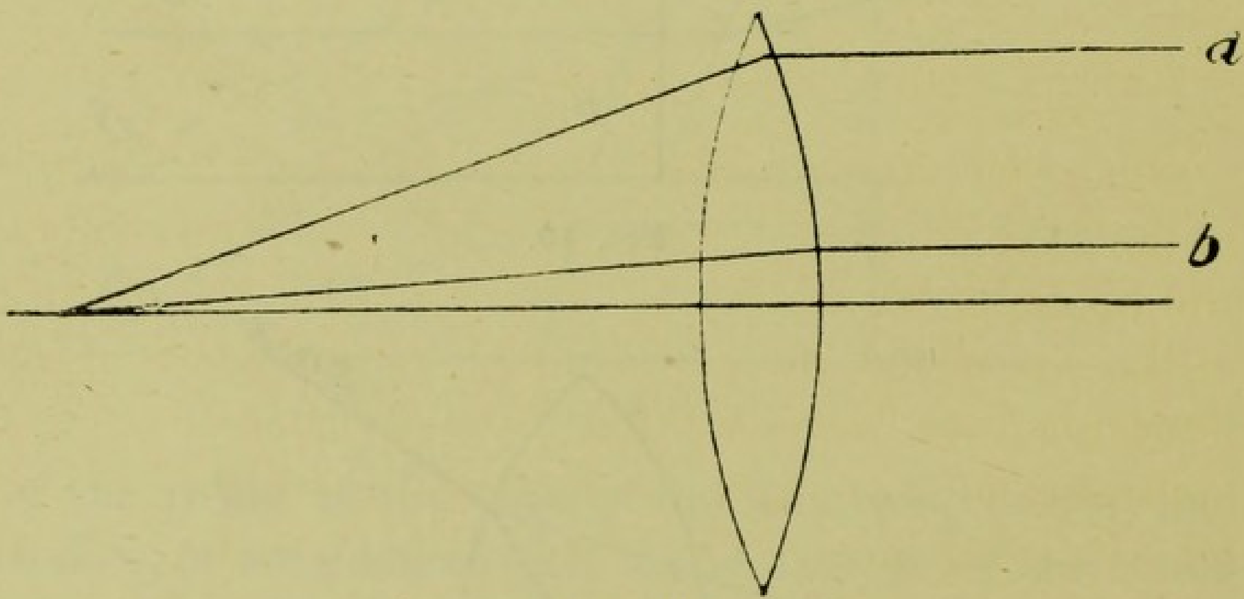


FIG. 12.

of a ray passing from one point to another is the same, whatever its direction. The path of the ray $b\,b'$, Fig. 13, is the same, whether it pass from $c\,f$ to $c'\,f'$ or the opposite. Referring to Fig. 7, it follows that in Fig. 13 the angles *a* and a' are equal, and hence the ray *b*, diverging from $c\,f$, will not meet the axis at *f*, but at $c'f'$. $c\,f$ and $c'\,f$ are conjugate points, and each is the conjugate focus of the other, the angle *a* or a' remaining the same; then if $c\,f$ be further from the lens, $c'\,f'$ will approach it, a ray *c* directed towards the axis will be focussed at $c''\,f''$, it will, on taking the direction c, appear to have come from $v\,f$, which consequently is the virtual focus of $c''\,f''$.

Foci of Lenses.—All the foci of concave lenses are virtual. In Fig. 14 the ray d, parallel to the axis, is made divergent, its virtual focus being at f; similarly $c\,f$ is the virtual conjugate focus of the point emitting the ray b in lenses equally bi-concave or bi-convex of crown glass. The principal focus is at the centre of the curvature of either surface of the lens. The image formed by a lens consists of foci each of which corresponds to a point on the object; given the foci of the boundary points of an

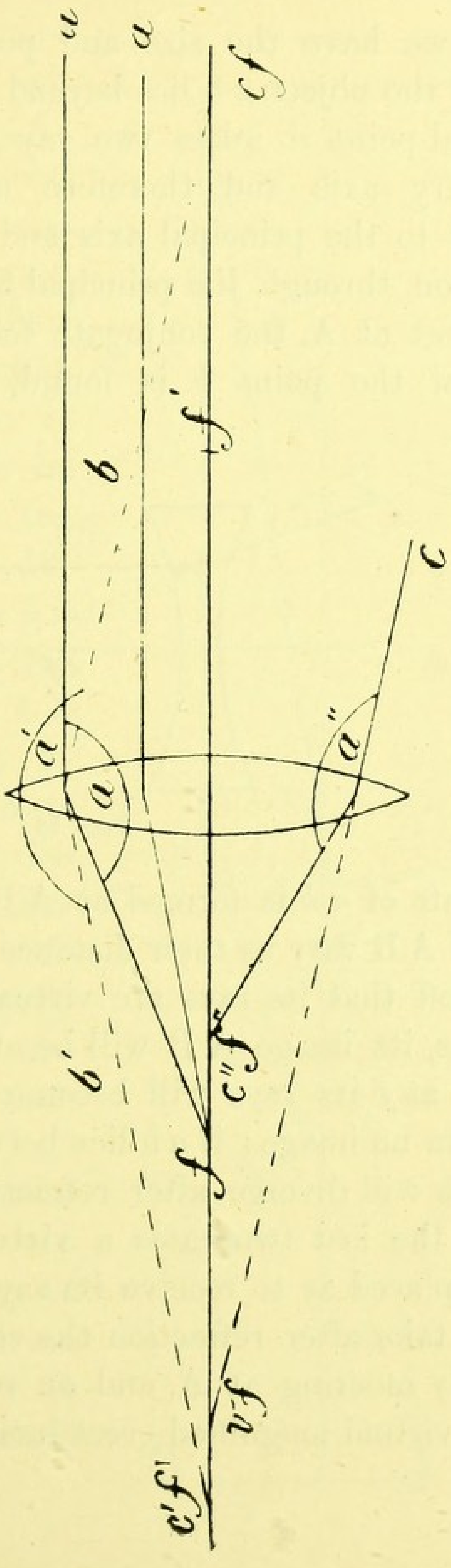


Fig. 13.

object, we have the size and position of its image. In Fig. 15 the object *a b* lies beyond the focus *f*. From the terminal-point *a* takes two rays, *a* and *a′*, the former a secondary axis and therefore unrefracted; the latter parallel to the principal axis and therefore passing, after refraction, through the principal focus *f′*. These two rays will meet at A, the conjugate focus of *a*. Similarly the focus of the point *b* is found, and the real inverted

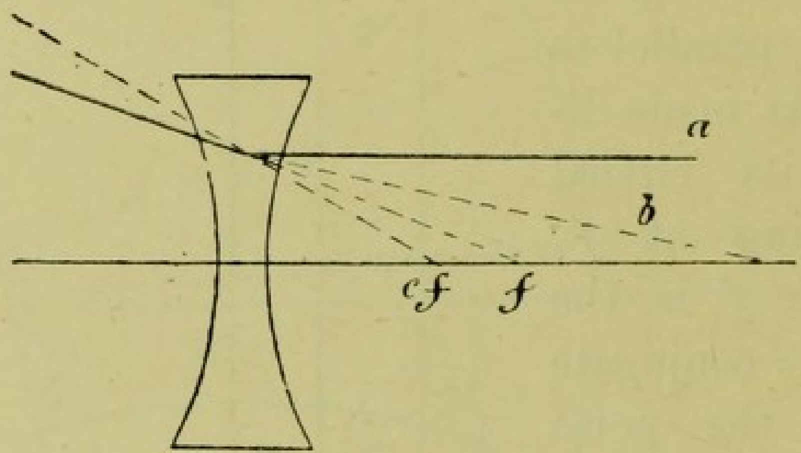


Fig. 14.

conjugate of *a b* is formed at A B. The relative sizes of *a b* and A B vary as their distance from the lens. If *a b* be so far off that its rays are virtually parallel on reaching the lens, its image A B will be at *f′*, and very small. If *a b* be at *f* its rays will become parallel after refraction and form no image; if *a b* lies between *f* or *f′* and the lens, the rays will diverge after refraction, and form no image. But in the last two cases a virtual image is seen by an eye so placed as to receive its rays. In Fig. 16 two rays from *a* take after refraction the course shown by *a* and *a′*, virtually meeting at A, and an observer at *x* will see at A B a virtual magnified erect image of *a b*. The enlargement (Fig. 16) is greater the nearer $a\ b$ is to f', and greatest when it is at f'; but as A B has no real existence, its apparent size varies with the estimated distance of the surface against which it is projected.

A uniform distance of projection of about 12 in. is taken in comparing the magnifying power of different lenses. When $a\ b$ is at f', Fig. 16, we shall find on trial, that the image A B can be seen well only by bringing the eye close up to the lens; at a greater distance only part of the image will be seen, and this part will be less brightly illuminated. This is important in direct ophthalmoscopic examination.

In Fig. 17 an observer placed anywhere between the lens and x receiving rays from the path of $a\ b$ will see the whole image; but if he withdraws to y, his eye will

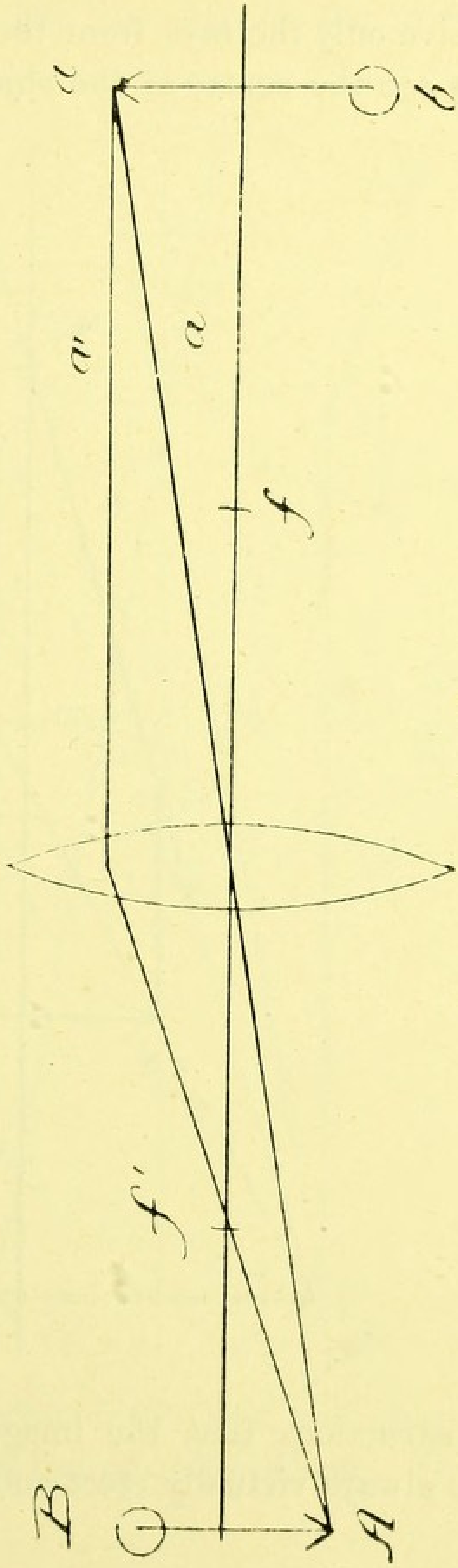


Fig. 15.

receive only the rays from the central part of *a b*, and will only see the centre of the object. It is shown by similar

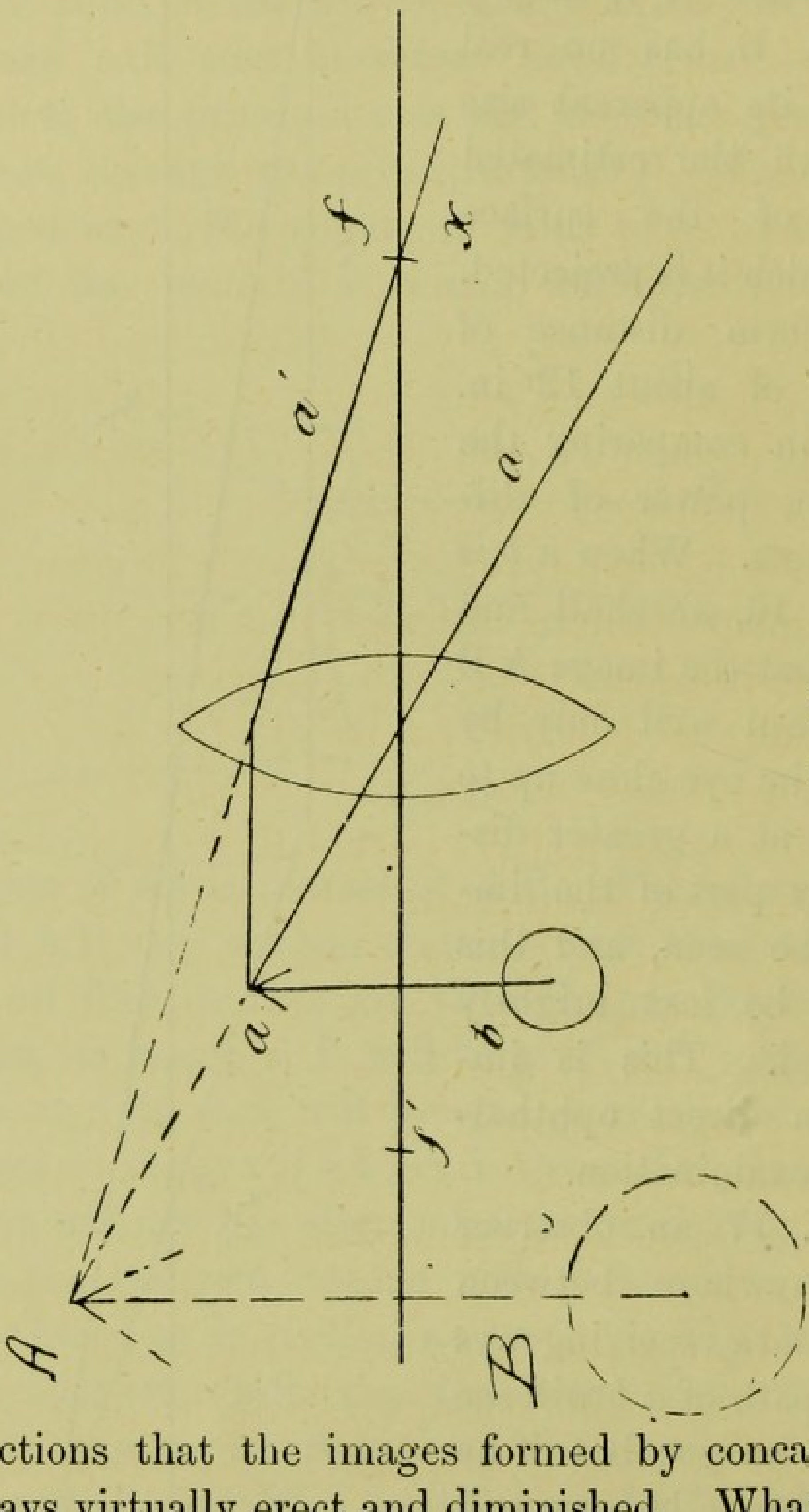


FIG. 16.

constructions that the images formed by concave lenses are always virtually erect and diminished. Whatever the distance of the object (Fig. 18), the size of the image

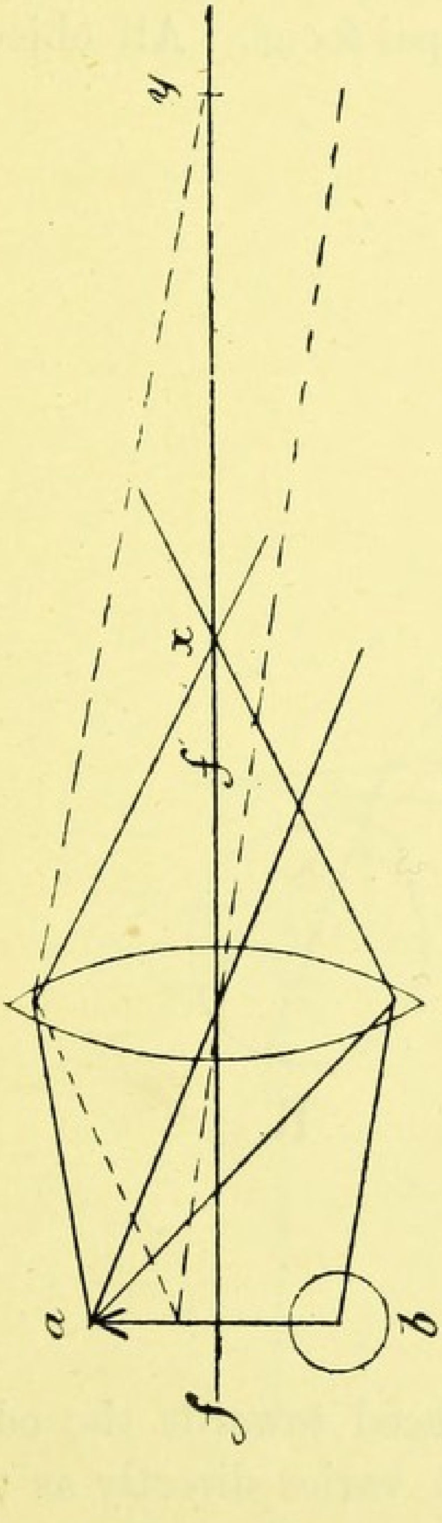


Fig. 17.

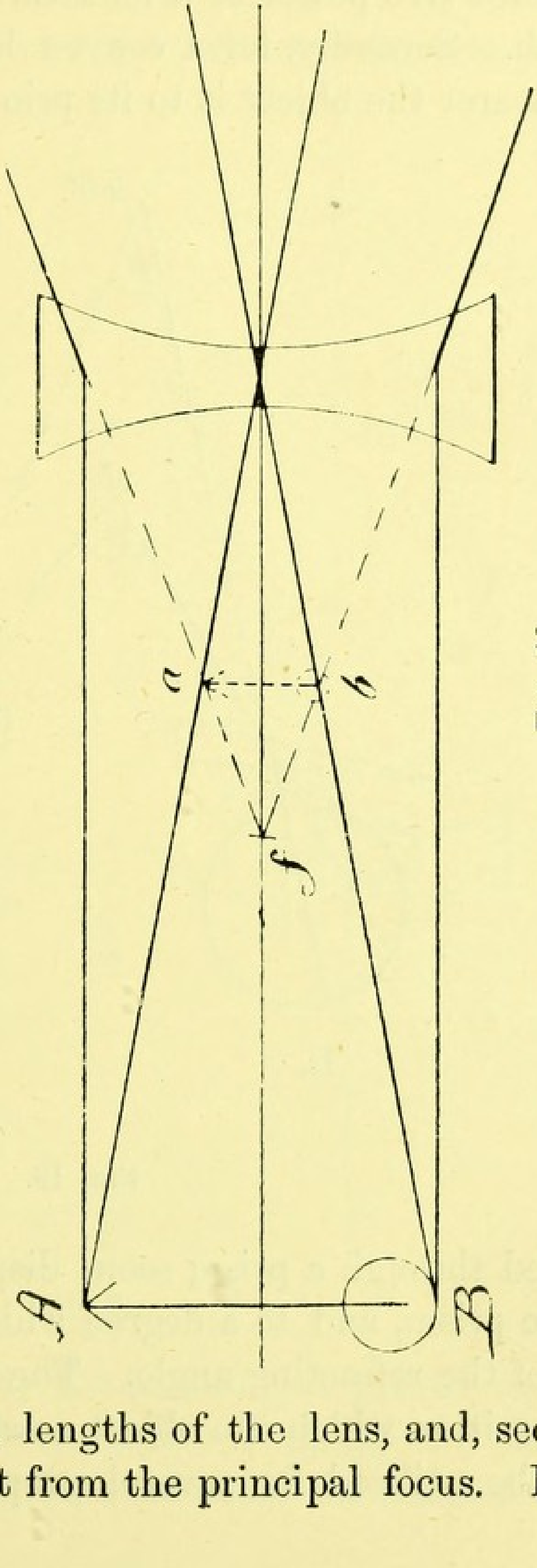


Fig. 18.

varies, first, by the focal lengths of the lens, and, second, the distance of the object from the principal focus. First, the shorter the focus of the lens, the greater is its effect: the refractive power of a lens varies inversely as its focal length. Secondly, for a convex lens the image is larger the nearer the object is to its principal focus. All objects

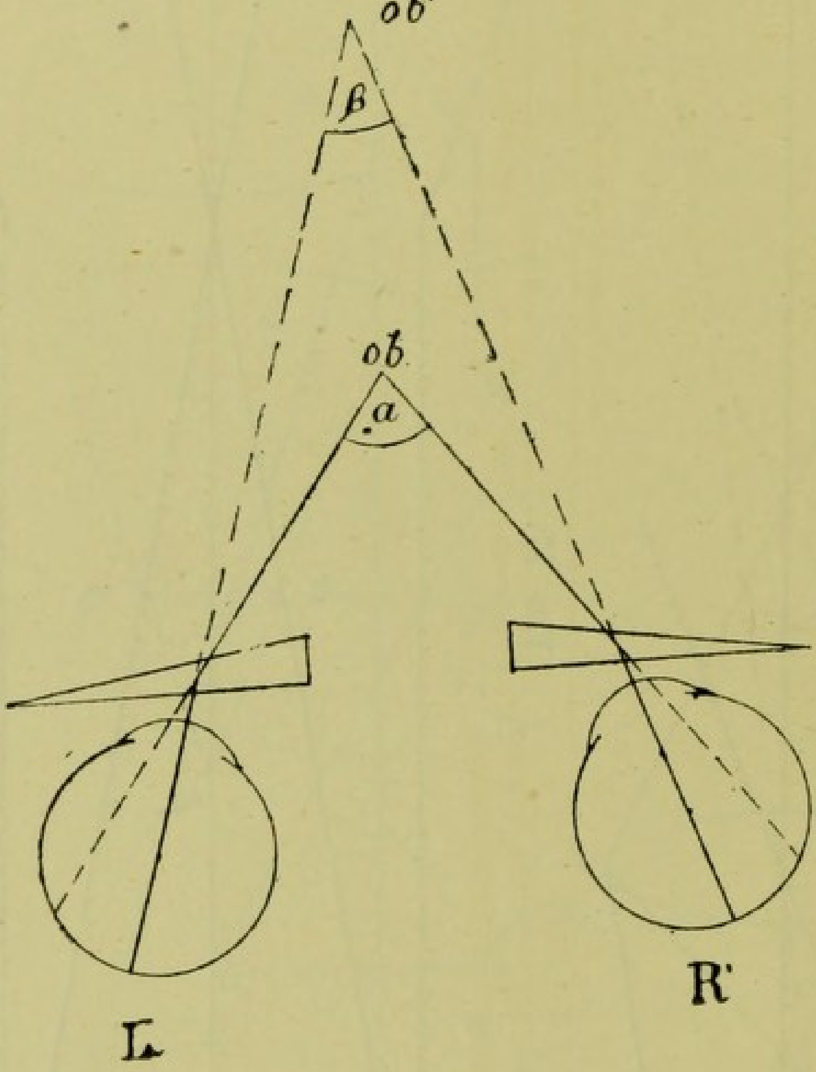


Fig. 19.

viewed through a prism seem displaced towards the edge of the prism, and to a degree which varies directly as the size of the refracting angle. The eye is directed towards the position which the object now seems to take, and this may be utilized for several purposes: (1) To lessen the convergence of the visual lines, without removing the object further from the eyes. In Fig. 19 the eyes R and L are looking at the object *o b*, with a convergence of the

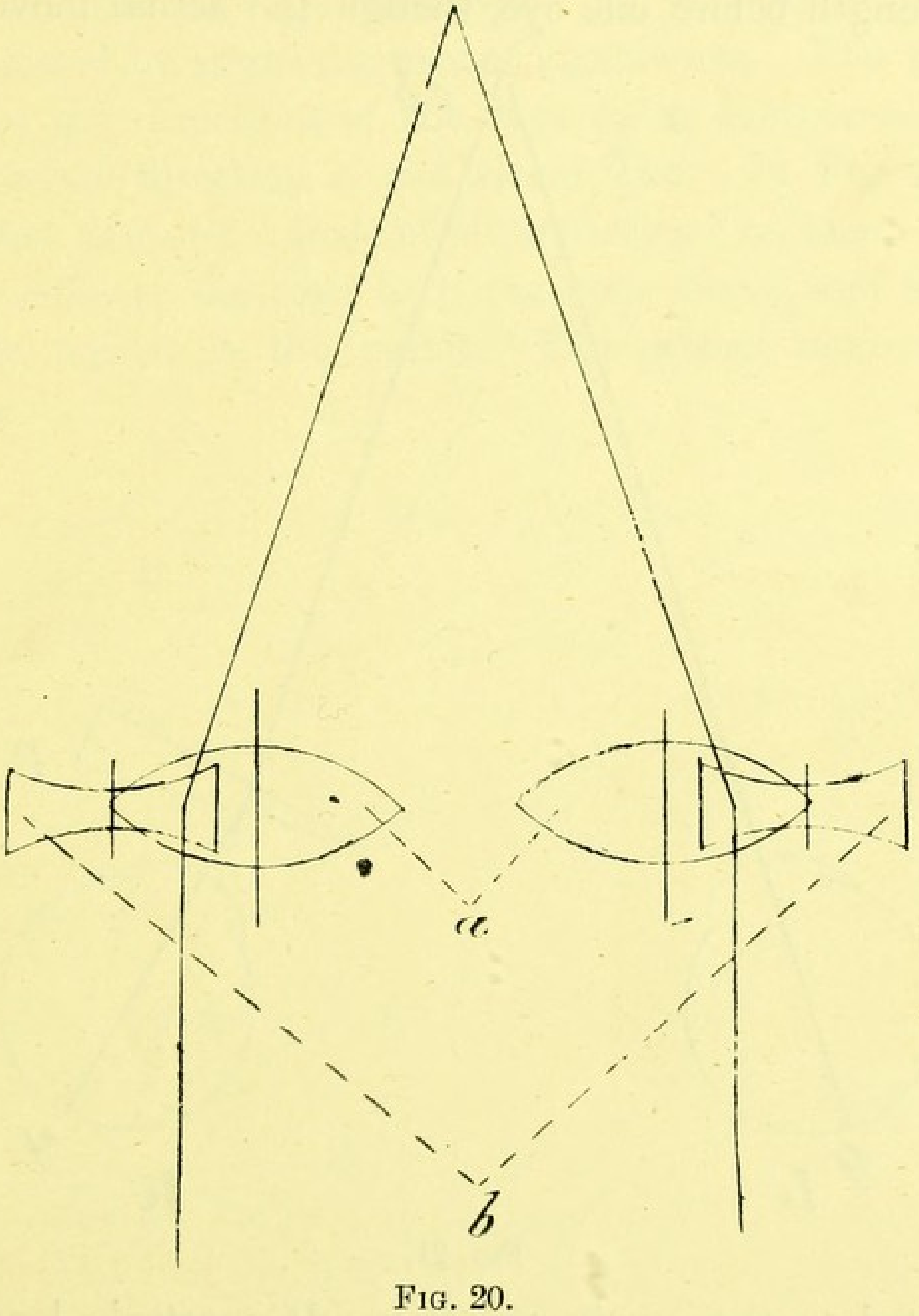


Fig. 20.

visual lines represented by the angle *a*; if prisms be now added with their edges towards the temples, they deflect the light so that it enters the eyes under the smaller angle

β as if it had come from *o b′*, and towards this point the eyes will be directed, though the object still remains at *o b*. The same effect is given by a single prism of twice the strength before one eye, though the actual movement

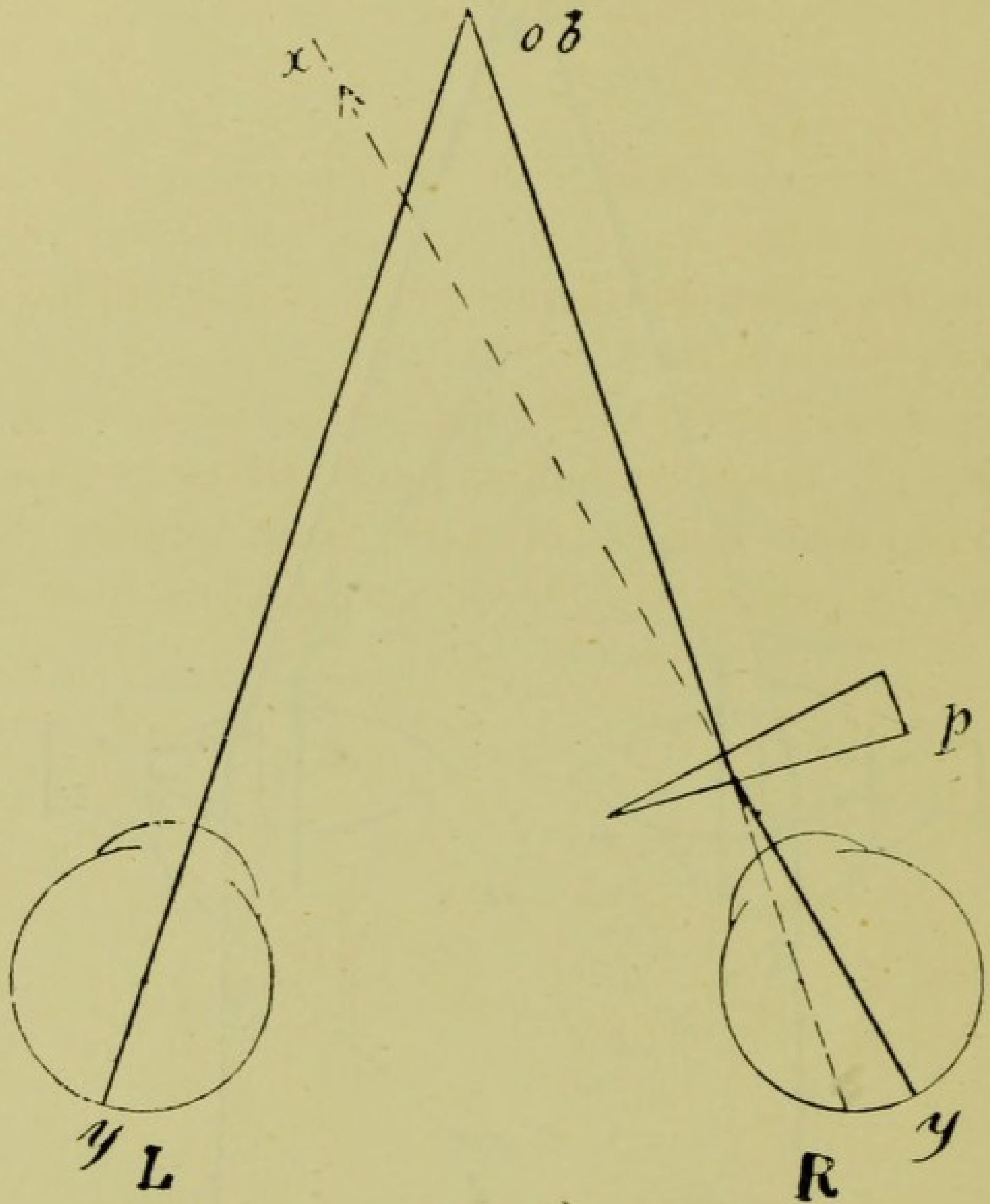


Fig. 21.

is limited to the eye in question. If spectacle lenses be placed so that the lines do not pass through the centres, they act as prisms, though the strength of the prismatic action varies with the power of the lens, and the amount of this decentration. In Fig. 20 the visual lines pass outside the centres of the convex lenses *a*, and inside those of the concave lenses *b*. Each pair, therefore, acts as a prism with its edge outwards. (2) To remove double vision caused by slight degrees of strabismus. The prism so alters the directions of the rays as to compensate for the abnormal direction of the visual line. In Fig. 21 R is directed towards *x* instead of towards *o b* as seen. The prism *p* deflects the rays to *y*, the optic nerve, and single binocular vision is the result. The prisms remove the diplopia.

CHAPTER III

ABERRATIONS OF THE EYE

Emmetropia-ametropia.—When the length of the eye is normal, and the accommodation relaxed (see Chapter II), only parallel rays are focussed on the retina, and conversely only pencils of rays emerging from the retina are parallel on leaving the eye, and this, the condition of the normal eye in distant vision, is called

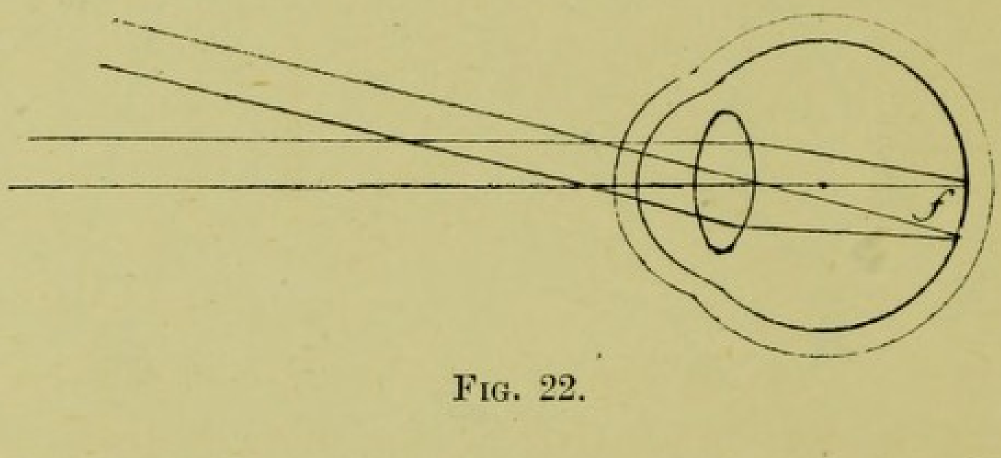


Fig. 22.

emmetropia. Fig. 22 shows pencils of parallel rays entering or emerging from an emmetropic eye. All permanent departures from the condition in which, with relaxed accommodation, the retina lies at the principal focus, are known as ametropia. In emmetropia rays from any near object are focussed behind the retina at *f* (Fig. 22), every conjugate focus being beyond the principal focus. Reaching the retina before focussing, such rays

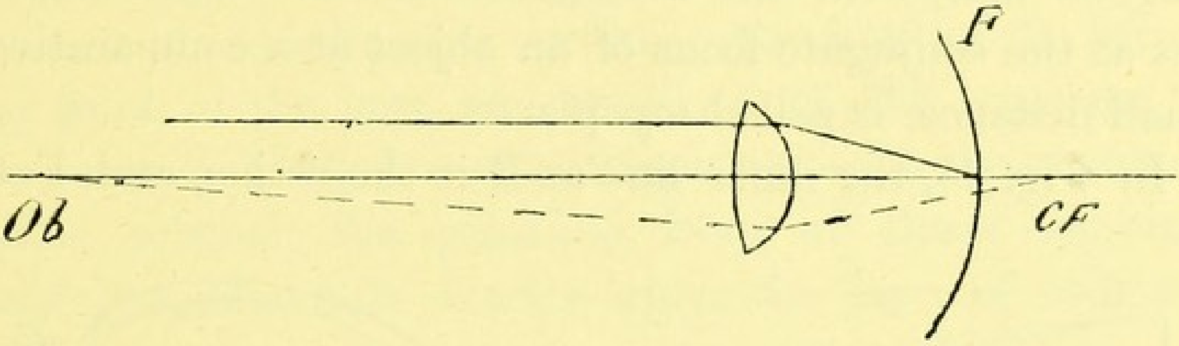


FIG. 23.

will form a blurred image, and the object *o b*, Fig. 23, will only be seen dimly.

MYOPIA.—But by using accommodation, the convexity of the crystalline lens can be increased and its focal length shortened, so as to make the conjugate focus of *o b* coincide exactly with the retina, as in F, Fig. 24. Under the

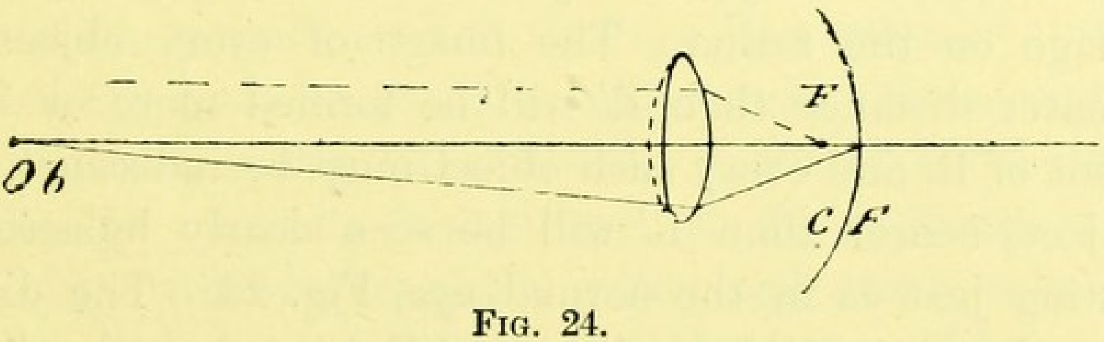


FIG. 24.

condition shown in Fig. 24, the object will be seen distinctly, whilst the focus of a distant object, which in Fig. 23 was formed on the retina, will now lie in front of it, F, Fig. 24, and the distant object will appear indistinct. In Fig. 23, if the retina was at C F instead of at F, a clear image would be formed of an object at *o b* without any effect of accommodation, whilst objects further off would be focussed in front of the retina. This state, in which the posterior part of the eyeball is too long, so that, with the accommodation at rest, the retina lies at the conjugate focus of an object at a comparatively small distance, is called myopia.

In Fig. 25, the inner line at R is the retina, and F the

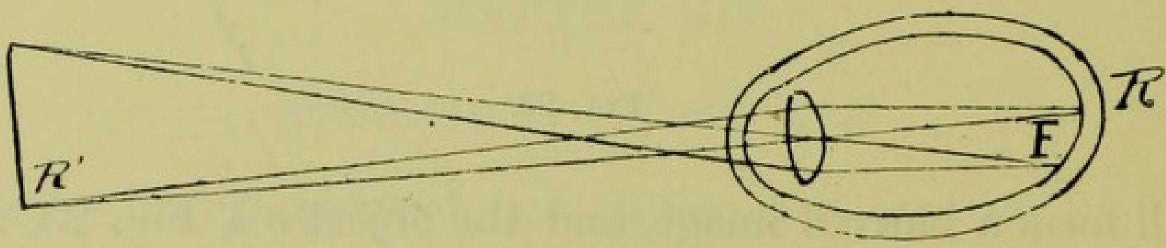


FIG. 25.

principal focus of the lens system. Rays emerging from R will, on leaving the eye, be convergent, and, meeting at the conjugate focus R′, will form a clear image in the air; conversely, an object at R′ will form a distinct image on the retina. The image of every object at a greater distance than R′ will be formed more or less in front of R, and every such object must be indistinct. But objects nearer than R′ will be seen clearly by accommodating just as in the normal eye, Fig. 23. The distance of *r* (R′, Fig. 25) from the eye will depend on the distance of its conjugate focus R—that is, on the amount of the elongation of the eye. The greater the distance of R beyond F the less will be the conjugate focus R′, and the more indistinct distant objects will become. If the elongation of the eye be very slight, R nearly coinciding with F, R′ will be at a greater distance, and distant objects will be more distinct. All images in a myopic eye are of larger magnification than in the normal eye. Consequently myopic persons can distinguish smaller objects at a greater distance than can people with normal eyes. The eye presents three refracting surfaces: the front of the cornea, the front of the lens, and the back of the lens, and in the normally formed or emmetropic eye with the accommodation relaxed, the principal focus of those combined dioptric media falls exactly upon the layer of rods and

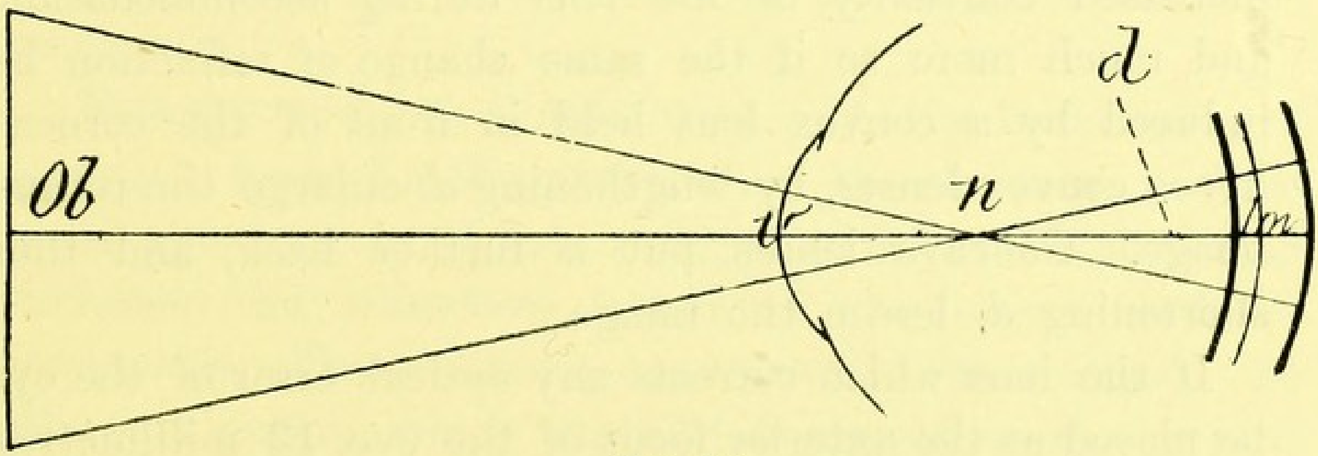


FIG. 26.

cones of the retina—that is, the eye in a state of rest is adapted for parallel rays. The point at which the secondary axial rays (see *n*, Fig. 26) cross the posterior nodal point lies, in the normally-formed eye, at 15 millimètres in front of the yellow spot of the retina, and nearly coincides with the posterior pole of the crystalline lens. The angle included between the lines joining *n*, Fig. 26, with the extremities of the object *o b* is the visual angle *v*. If the distance *d* from *n* to the retina remains the same, the size of any image 1 *m*, Fig. 26, on the retina will depend on the size of the angle *v*, and this again on the size and distance of the object. But if the distance *d* alters, the size of the image is altered without any change in *v*.

Now if the length of *d* varies with the posterior segment of the eye, it is greater in myopia and less in hypermetropia, and hence the retinal image of an object at a given distance is larger in myopia and smaller in hypermetropia than in the normally-formed eye. The length of *d* also varies with the position of *n*, and this is influenced by the positions and the curvatures of the several refractive surfaces; *n* is slightly advanced by the increased convexity of the lens during accommodation, and much more so if the same change of refraction be induced by a convex lens held in front of the cornea; hence convex lenses, by lengthening *d*, enlarge the retinal image. Concave lenses put *n* further back, and thus shortening *d*, lessen the image.

If the lens which corrects any optical error of the eye be placed at the anterior focus of the eye, 13 millimètres, or half an inch in front of the cornea, *n* moves to its normal distance, 15 millimètres from the retina, and the images are, therefore, reduced or enlarged to the same size as in the emmetropic eye. The length of the visual axis, a line drawn from the yellow spot to the cornea in the direction of the object looked at, is about 23 millimètres. The centre of the rotation of the eye is rather behind the centre of this axis, and 6 millimètres behind the back of the lens. The focal length of the cornea is 31 millimètres, and that of the crystalline lens varies from 43 millimètres, with accommodation relaxed, to 33 millimètres during strong accommodation.

Optical Conditions of Clear Sight.—Many of the previous diagrams are similar to those in Mr. Nettleship's *Student's Guide to Diseases of the Eye*, and which I shall employ to show the uses of the different ophthalmoscopes, to be described hereafter. The optical conditions of clear sight are as follows:—1. The image must be clearly focussed on the retina. 2. It must be formed at the centre of the yellow spot. 3. It must have a certain size, and this is expressed by the size of the corresponding visual angle. 4. The cornea, lens, and vitreous humour must be clear. 5. The illumination must be sufficient.

Numeration for Correction.—In the numeration of spectacle lenses for the correction of the aberrations of the eyes, some system of numbering is required which should indicate the refractive power of the lenses used for spectacles. Two systems are current (Nettleship). In the first system, which was till latterly universal, the unit of strength is a strong lens of 1 in. focal length. As all the lenses used are weaker than this, their relative strengths can be expressed only by using fractions. Thus a lens of 2 in. focus, being half as strong as the unit 1 in., is expressed as $\frac{1}{2}$. A lens of 10 in. focus $\frac{1}{10}$ of 20 in., is $\frac{1}{20}$, and so on. The objections are inconvenient in practice, that the intervals between the successive numbers are very unequal, and that the length of the inch is not the same in all countries—so that the glass of the same number has not quite the same focal length when made by the Paris, English, and German inches respectively. The English inch equals 25·3 millimètres; the French inch equals

27· millimètres; the Austrian inch equals 26·3 millimètres; the German inch 26·1 millimètres.

In the second system, which has displaced the old one, the metrical scale is used. The unit in a weak lens of one mètre (100 centimètres) is 10 D, and so on. The weakest lenses are ·25, ·5, and ·75 D, and numbers differing by ·5 or ·25 D are also introduced between the whole numbers. A slight inconvenience of the metrical dioptric system is that the number of the lens does not express its focal length. This, however, is obtained by dividing 100 by the number of the lens in D; thus the focal length of 4 D = $\frac{100}{4}$ = 25 centimètres. If it be desired to convert one system into the other, this can be done, provided that we know which inch (whether English, French, etc.) was used in making the lens, whose equivalent is required in D. The mètre is equal to about 37 in. French and 39 in. English or German; a lens of 36 in. French (No. 36 or $\frac{1}{36}$ old scale) or of 40 in. English or German (No. 40 or $\frac{1}{40}$) is nearly the equivalent of 1 D. A lens of 6 in. French ($\frac{1}{6} = \frac{6}{36}$) will therefore be equal to 6 D. A lens of 18 in. French ($\frac{1}{18} = \frac{2}{36}$) = 2 D, etc. The following lenses are used for spectacles, and are therefore necessary in a complete set of trial glasses. The first column gives the number in D, the second the focal length in centimètres, the third the approximate numbers on the French *inch scale*, the denominator of each fraction showing the focal length in French inches. It will be seen that some metrical lenses have no exact equivalents on the inch system.

D. Dioptres.	Focal Length in C.M.	No. and Focal Length in Paris Inches.
0·25	400	—
0·5	200	1/72
0·75	133	1/50
1	100	1/36
1·25	80	1/30
1·5	66	1/24
1·75	57	1/22
2	50	1/18
2·25	44	1/16
2·5	40	1/14
2·75	36	1/13
3	33	1/12
3·5	28	1/10
4	25	1/9
4·5	22	1/8
5	20	1/7
5·5	18	—
6	16	1/6
7	14	1/5½
8	12·5	1/4
9	11	1/4
10	10	1/3½
11	9	—
12	8·3	1/3
13	7·7	—
14	7	1/2¾
15	6·7	1/2½
16	6·2	1/2¼
18	5·5	1/2
20	5	—

CHAPTER IV

EXAMINATION OF THE EYE—THE OPHTHALMOSCOPE

In the examination of the eye by lenses and mirrors, the focal or oblique illumination of the anterior part of the eye can be examined by concentrating the light of a lamp on the part by a convex lens. The method is used to detect or examine opacities of the cornea, etc. Such an examination is generally used in every case before bringing in the aid of the ophthalmoscope.

To make a preliminary examination of an eye, we shall require a convex lens of 3 in. focus, which is supplied with all ophthalmoscopes, and a naked lamp-flame. The lens is held between the finger and thumb at about its own focal length from the eye and the lamp, which should be 24 in. away from the eye to be examined. The lens being in the line of light, you will be enabled to throw a bright pencil on the front of the eye at an angle with the observer's line of sight. In this way, all parts of the eye—the cornea, the iris, or the anterior or posterior surfaces of the crystalline lens—may be examined, as is shown in Fig.

27. By varying the position of the lens, and causing the eye to be moved, all parts can be thoroughly examined.

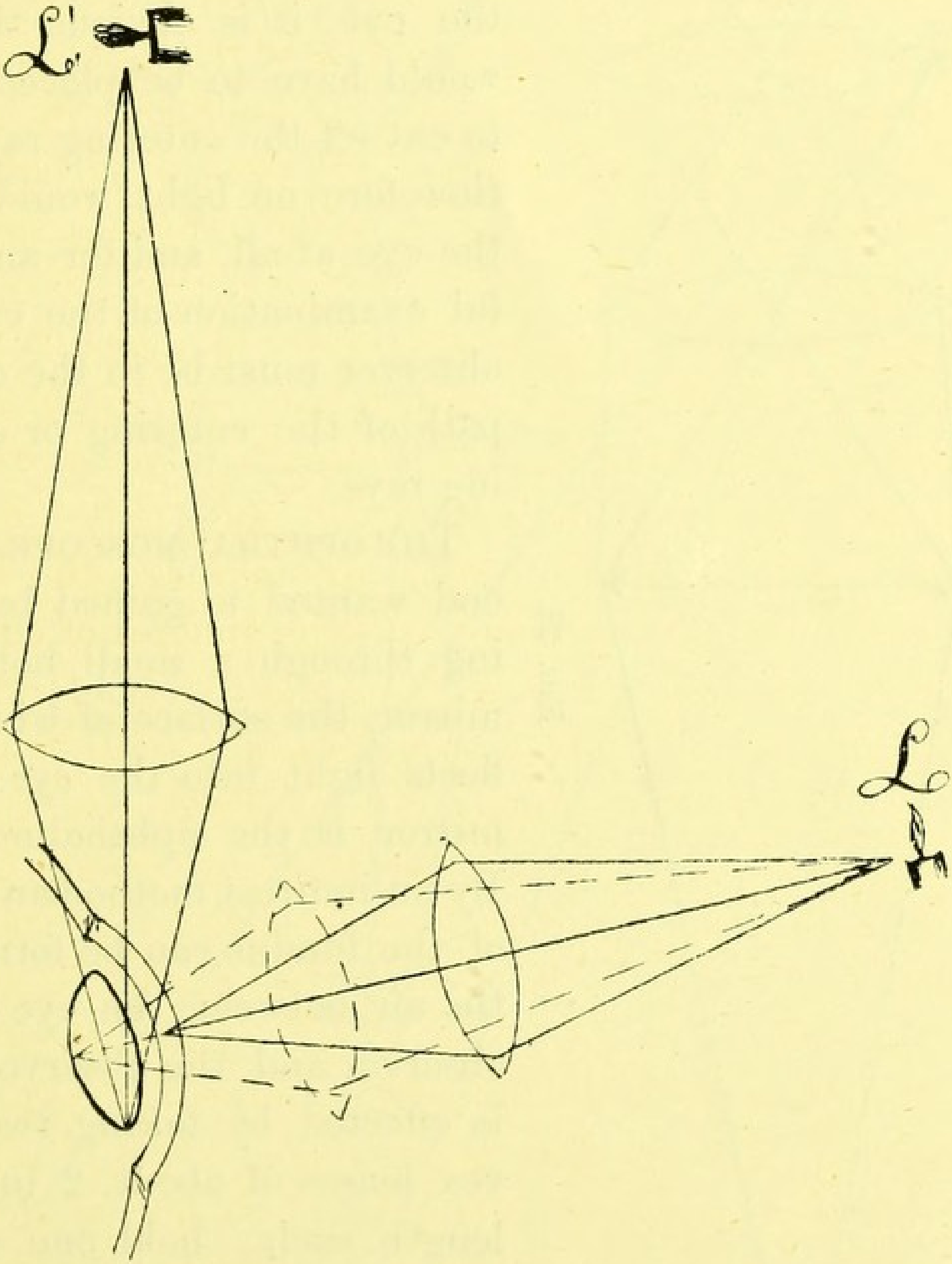


FIG. 27.

Rays of light entering the pupil in a given direction are partly reflected back by the choroid and the retina, and on emerging from the pupil, take very nearly the same course

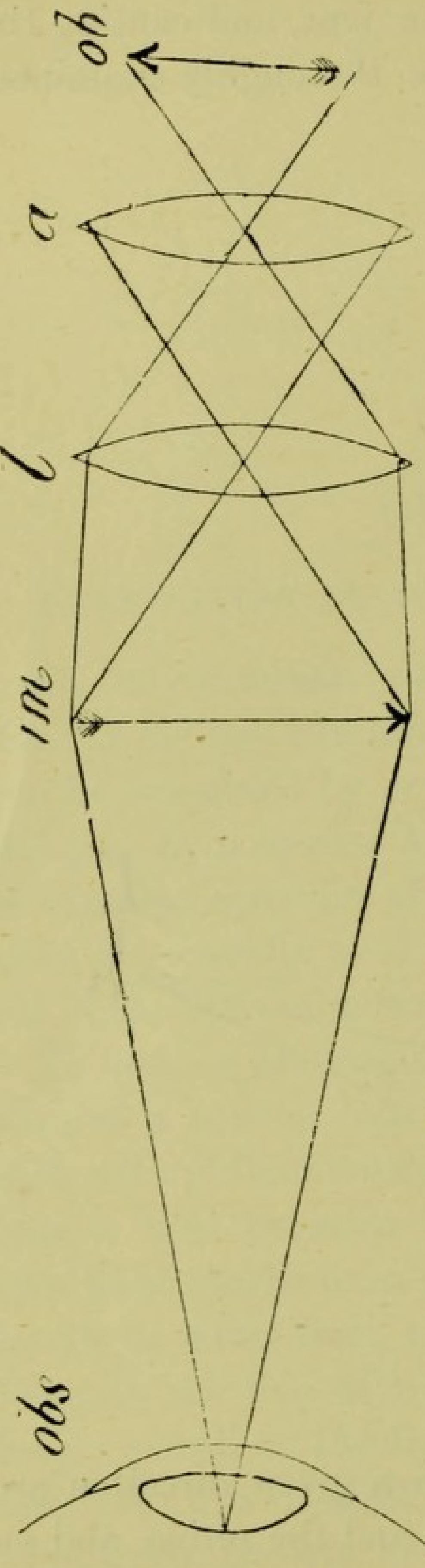


Fig. 28.

they had on entering. Therefore, if the observer wishes to make a close examination of the eye, it is obvious that he would have to be placed so as to cut off the entering rays, and therefore no light would enter the eye at all, and for any useful examination of the eye the observer must be in the central path of the entering or emerging rays.

The ophthalmoscope.—The end wanted is gained by looking through a small hole in a mirror, the surface of which reflects light into the eye. This mirror is the ophthalmoscope. By an indirect method an image of the fundus can be formed in the air between the eye of the observer and the observed, and is effected by taking two convex lenses of about 2 in. focal length each; hold one in the left hand about 2 in. from any object you wish to view, take the other in the right hand, and moving your head a few inches back, hold the second lens at its focal length in

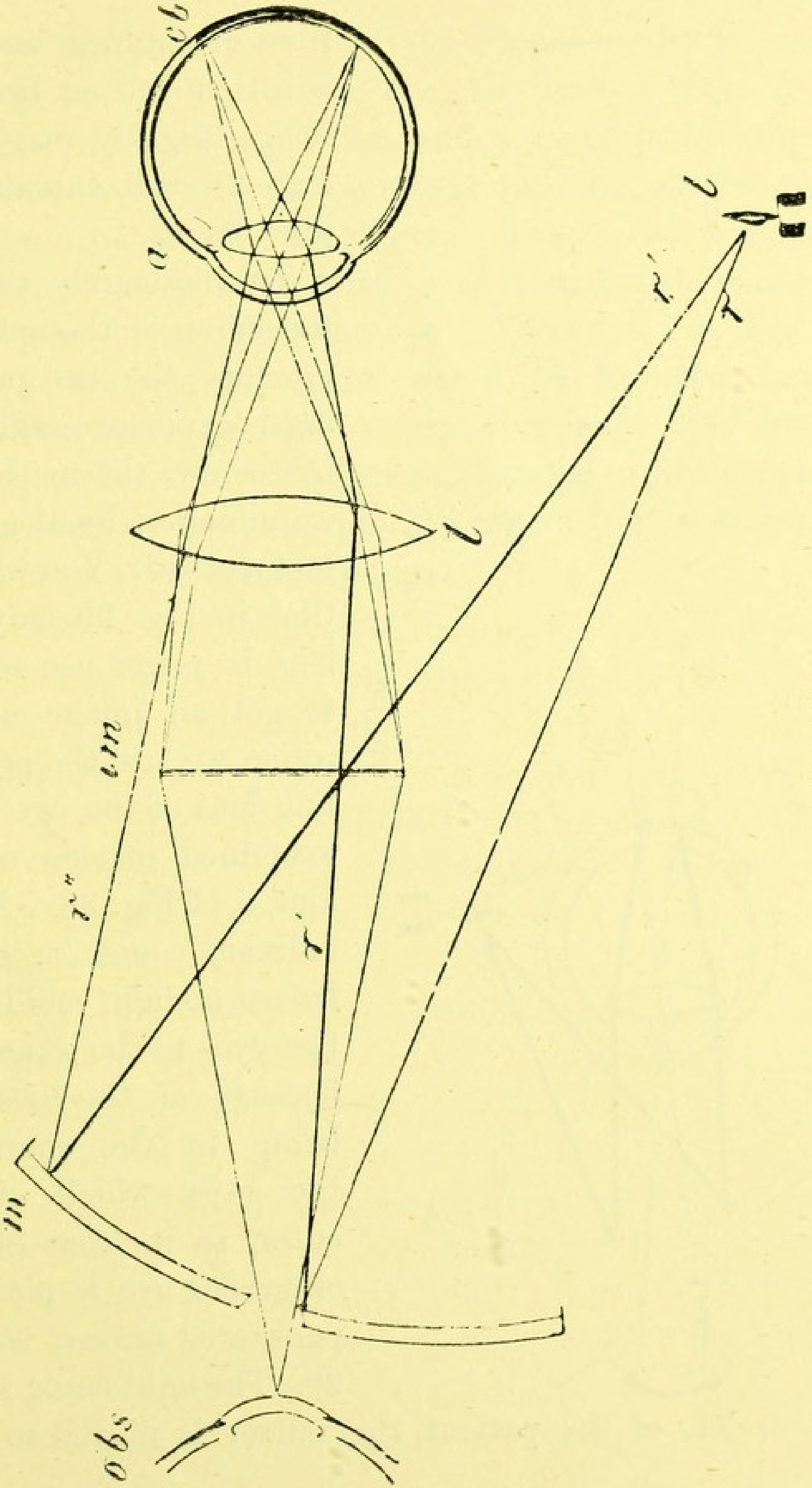


FIG. 29.

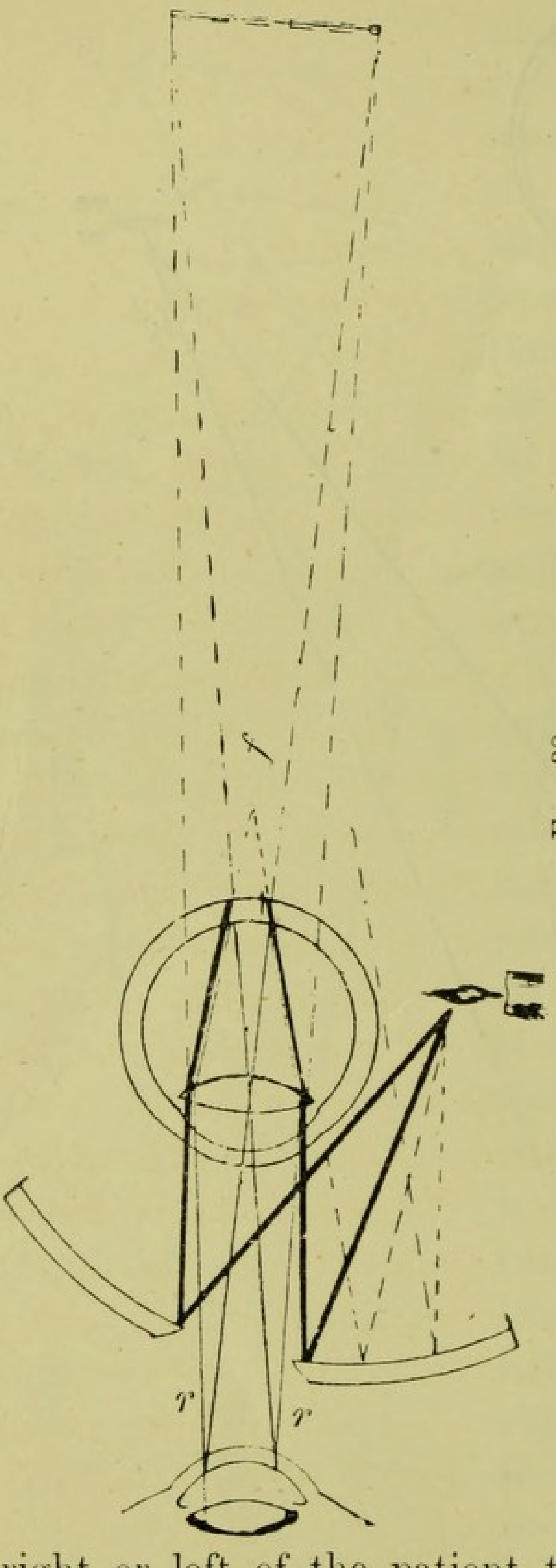


Fig. 30.

front of the first one, you will then see an inverted image slightly magnified. Fig. 28 will explain the phenomena.

To thoroughly explain the action of the ophthalmoscope, the two preceding diagrams are sufficient. One shows the method of examination by the indirect method. You will see that in Fig. 29 only one lens is made use of, and to get an image of the retina we use the crystalline lens of the eye to be examined instead of the lens, *a*, of Fig. 28. In the ordinary course, as stated before, no light could enter the eye to be examined because of the observer being in the course of the rays which should enter, so in front of the observer's eye is placed a perforated mirror, *m*, Fig. 29. The light being to the right or left of the patient, the mirror is moved so that a ray of light incident from the frame to the mirror is reflected into the patient's eye, the lens, *l*, Fig. 29, is moved to a suitable position, and a magnified image of the retina is formed between this and the observer. In the examination of virtual erect image, the lens, *l*, in Fig. 29, is dispensed with, and the ophthalmoscopic mirror placed very near the eye. The rays, *r r*, Fig. 30, entering the eye divergent would be focussed behind the retina as at *f*, and hence illuminate the fundus diffusely. The returning pencils, parallel or divergent, on leaving the eye appear to proceed from a highly-magnified erect image at or behind the eye.

CHAPTER V

OPHTHALMOSCOPES AND THEIR USES

In using the ophthalmoscope by the direct method, the examination is made by the mirror alone or with the addition of a lens placed behind it between the back of the mirror and the eye of the observer, but with no lens between the mirror and the eye to be examined. These are called refraction ophthalmoscopes, and are made from the simple Liebreich to almost any degree of complication in construction, many of which I shall describe. By the method previously stated, the parts are seen in their true positions, and are used to ascertain the condition of the patient's refraction—the relation of his retina to the focus of his lens system; to detect opacities in the vitreous humour; for the minute examination of the fundus by the highly-magnified, erect image illustrated; for examining the iris, cornea, and crystalline lens with magnifying power.

When using the mirror alone to ascertain the refraction at a distance of 12 in. to 18 in. from the eye, we see some of the retinal vessels, the eye is either myopic or hypermetropic. If when the observer's head is moved slightly from side to side the vessels seem to move in the same direction, the image seen is a virtual one, and the eye hypermetropic. The eye is myopic if the vessels seem to move in the contrary direction. The image in myopia is formed and seen in the same way as the inverted image seen by the indirect method of examination; but, except in highest degrees of myopia, it is too large and too far from the eye to be observed to be useful for detailed examination.

In low degrees of myopia this image is formed so far in front as to only be visible when the observer is 3 ft. or 4 ft. distant, whilst in emmetropia and in the lower degrees of hypermetropia the erect image will not be easily seen at a greater distance than 12 in. to 18 in. If, therefore, the examiner has to go very near to or a great distance from the eye to get a clear image, no great error of refraction can be present. In emmetropia the erect image can be seen only if the observer be near to the patient and relax his accommodation.

In hypermetropia, where the retina is within the focus of the lens system, the erect image is seen when close to the patient's eye only by an effort of accommodation in the observer, just the same as in the experiment with the lens within its focal length of an object. As in that experiment the object was seen as well with the head withdrawn, so in hypermetropia the erect image is seen at a distance as well as close to the patient. Now if the observer, instead of increasing the convexity of his crystalline lens by an effort of accommodation, place a convex lens of equivalent power behind his mirror, this lens will be the measure of the patient's hypermetropia; it will be the lens which, when the patient's accommodation is in abeyance, will be needed to bring parallel rays to a focus on his retina. If a higher lens be used it will be the same as the experiment of the convex lens being placed beyond its proper focus—the fundus will be indistinct. To measure hypermetropia the accommodation of both observer and observed must be relaxed. The observer must go as close as possible to the patient, and place convex lenses behind the mirror of his ophthalmoscope, beginning with the weakest and increasing the strength till the highest is reached, which still permits the details of the yellow spot to be seen with perfect clearness. In the same way myopia can be measured by means of concave lenses, the lowest lens with which a clear, erect image is obtained being slightly more than the measure of the myopia.

It is sometimes useful to know how much lengthening or shortening of the eye corresponds to a given neutralizing lens, the distance between the eye of the observer and that of the patient not being more than 1 in.

Hypermetropia of	1 D	= shortening	of	·3 mm.
,,	2	,,	,,	·5 ,,
,,	3	,,	,,	1·0 ,,
,,	5	,,	,,	1·5 ,,
,,	6	,,	,,	2·0 ,,
,,	9	,,	,,	3·0 ,,
,,	12	,,	,,	4·0 ,,
,,	18	,,	,,	6·0 ,,

Myopia of	1 D	= lengthening of	·3 mm.	
,,	2	,,	,,	·5 ,,
,,	3	,,	,,	·9 ,,
,,	5	,,	,,	1·3 ,,
,,	6	,,	,,	1·75 ,,
,,	9	,,	,,	2·6 ,,
,,	12	,,	,,	3·5 ,,
,,	18	,,	,,	5·0 ,,

ASTIGMATISM.—Astigmatism of the eye may also be measured by this method, the refraction being estimated successively in the two chief meridians by means of appropriate retinal vessels. Any horizontal running vessel is seen by means of rays which pass through the meridian of the cornea at a right angle to its courses. Thus if a vertical vessel be seen clearly through a convex 2 D lens, there is hypermetropia 2 D in the horizontal meridian, etc.

THE LIEBREICH OPHTHALMOSCOPE.—We have seen what the ophthalmoscope has to do, and the conditions under which it is used. It remains, therefore, to describe some of the most prominent types. The simplest ophthalmoscope is after Liebreich. Fig. 31 shows it with a lens in the clip at the back, and Fig. 32 a section of same, showing mirror on one side and lens the other. With this instrument are supplied two convex lenses, of $2\frac{1}{2}$ in. and 4 in. focus, and four or five lenses concave and convex. When using it the lenses have to be placed in the clip in rotation. It will be seen that the hole in the mirror (which should be not less than two millimètres, and not over three, in diameter) being small, a very small part of the lens is used—only the extreme centre, and all the rest waste; but the small part required being separate would very soon be lost, so it is obvious that if a few lenses could be placed in a disc that would revolve in front of the hole in front of the mirror, it would be a great advantage over continually moving the different correctors from their

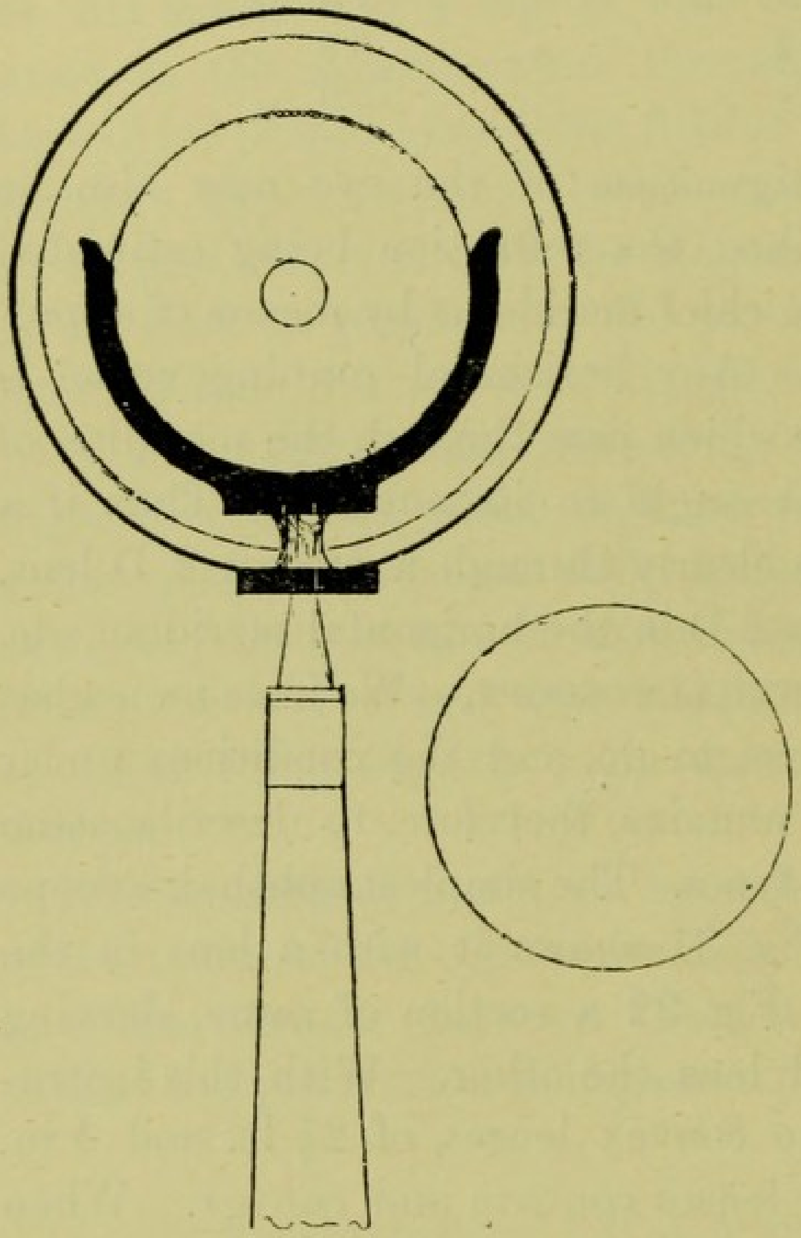


FIG. 31.

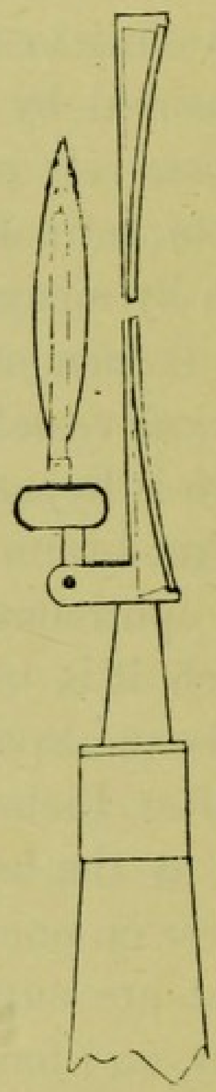


FIG. 32.

case to the clip, so that when a small disc was attached to the mirror, as Fig. 33, which could be swung on one side when necessary, it was a decided improvement.

An instrument, as we can see by Fig. 34, can be built up of two discs, being as large as convenient, and having as many lenses as wanted, and intermediate powers being

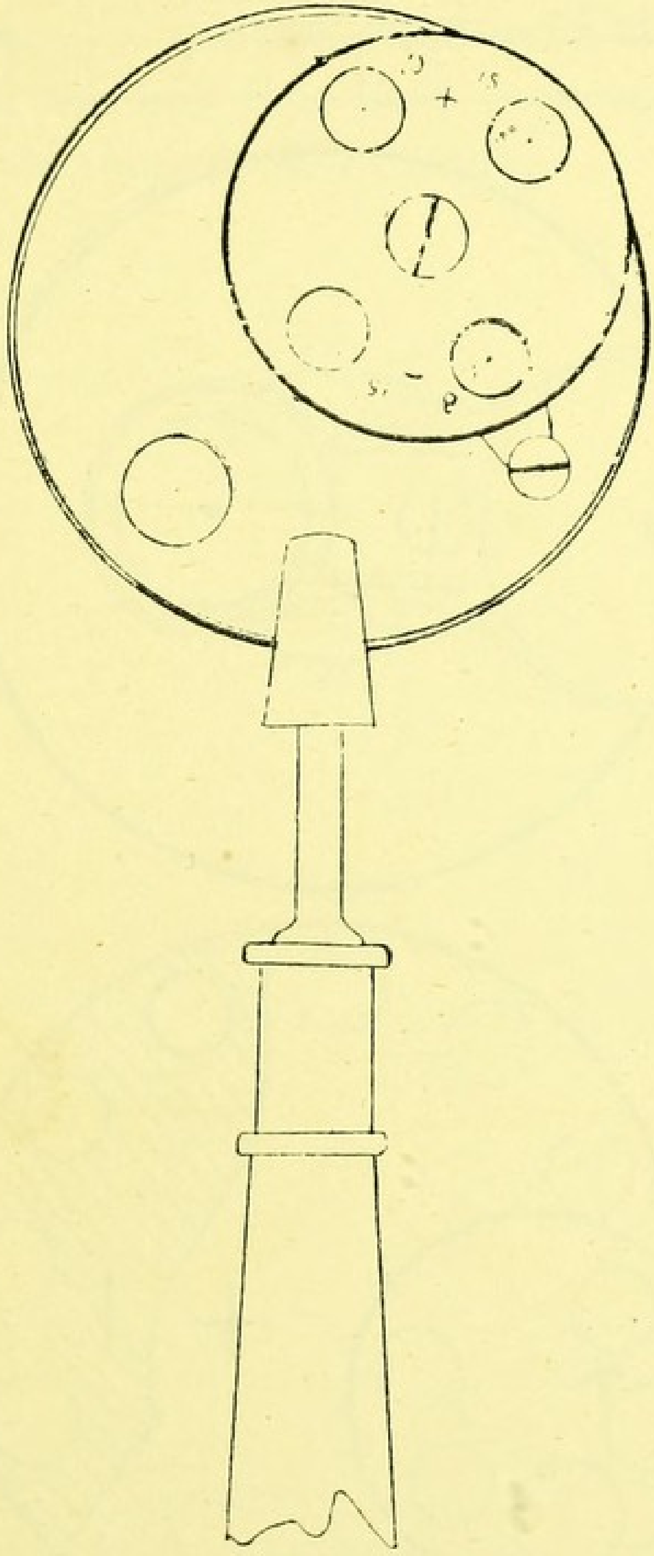


Fig. 33.

obtained by an extra disc, with the odd plus and minus lenses in, each disc having a plain aperture; one could be fastened whilst the other was used. This is the basis of

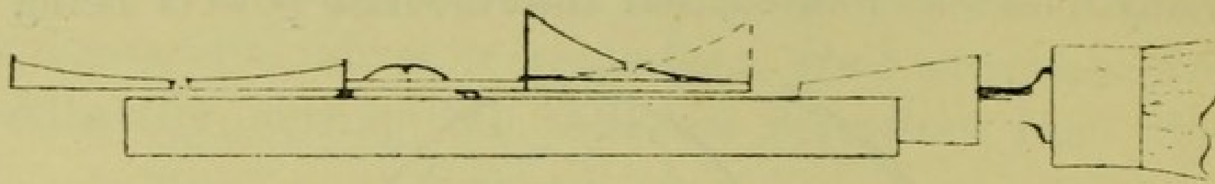


FIG. 36.

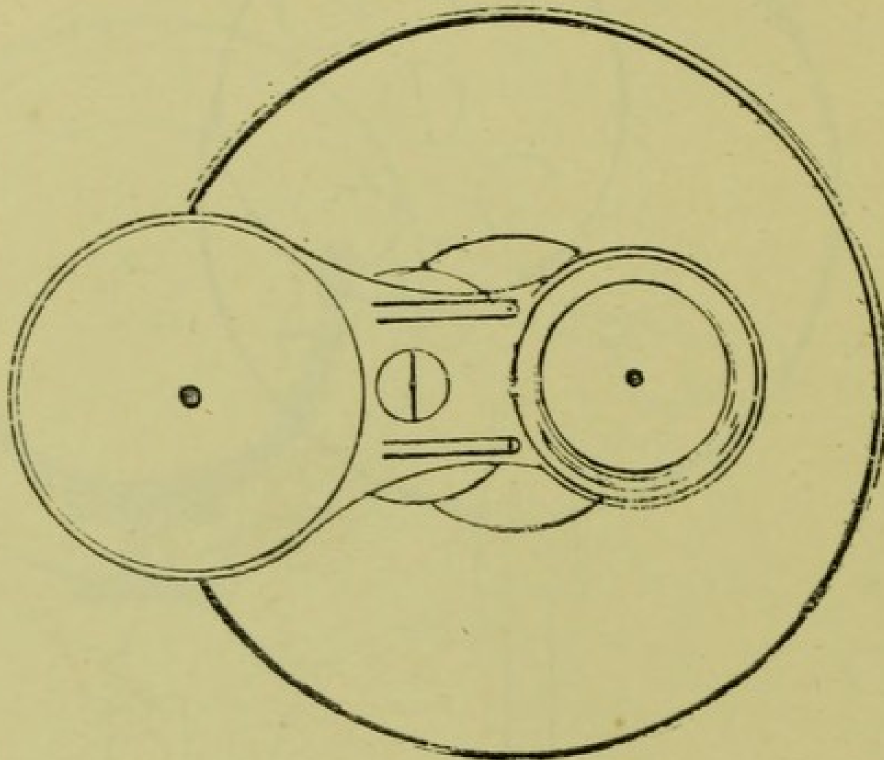


FIG. 35.

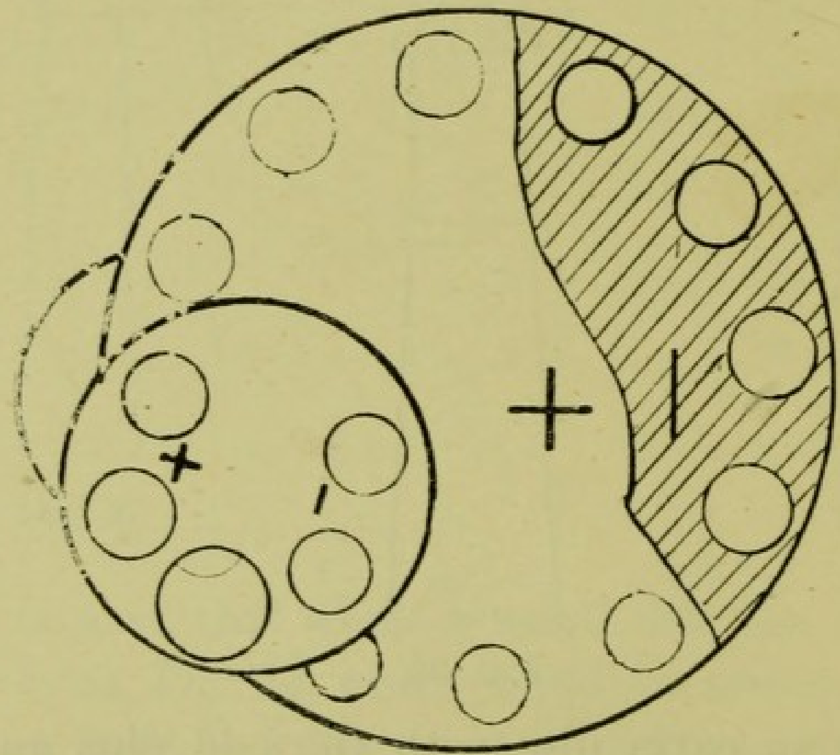


FIG. 34.

many constructions of ophthalmoscopes. The mirrors can be more than one on the principle of a swivel, as in Fig. 35, and can be canted to any angle, as shown in the section. These are the important parts of the instrument, and we shall see how they have been used to obtain the magnificent instruments now extant.

CHAPTER VI

THE MORTON OPHTHALMOSCOPE

It is not for me to say which is the best ophthalmoscope, as good results can be got in efficient hands from the simple Liebreich, but to describe the principles and construction of them. Those parts hitherto illustrated consist essentially of lenses in a disc; but the one I shall now describe is altogether on another principle.

Imagine a continuous chain of discs running round a groove, and we have the idea of the instrument. Now it should be obvious that this should be one of the best instruments that could be devised, for however small you made your lenses in the disc you could not have very many, unless you had your wheels so large that the ophthalmoscope would be very unwieldy and heavy; but by lengthening the magazine any amount of lenses may be used. Fig. 37 will show a magazine containing a number of small brass cells, and it will be seen that they will travel round and round, each one in its turn getting to the eye-hole, and with the addition of the other disc with the extra lenses in, you can get an enormous number of different magnifications, contained in a very limited area. On this principle is the Morton ophthalmoscope.

The magazine is made from thin sheet metal, knocked over to form the edge on a template. This is easily done if you anneal the metal from time to time. Knocking over is more certain than milling out, as it is impossible to vary in size, for it must be borne in mind that the cells, to work round, must be in a certain proportion to the body. If such is not the case, they will not perfectly fill up the channel, and a shake is the result. If this occurs, the lens that is supposed to be centred with the eye-hole will drop on one side, and the observer will be looking through the lens near its edge; or if very much so, the edge of the cell will even be visible.

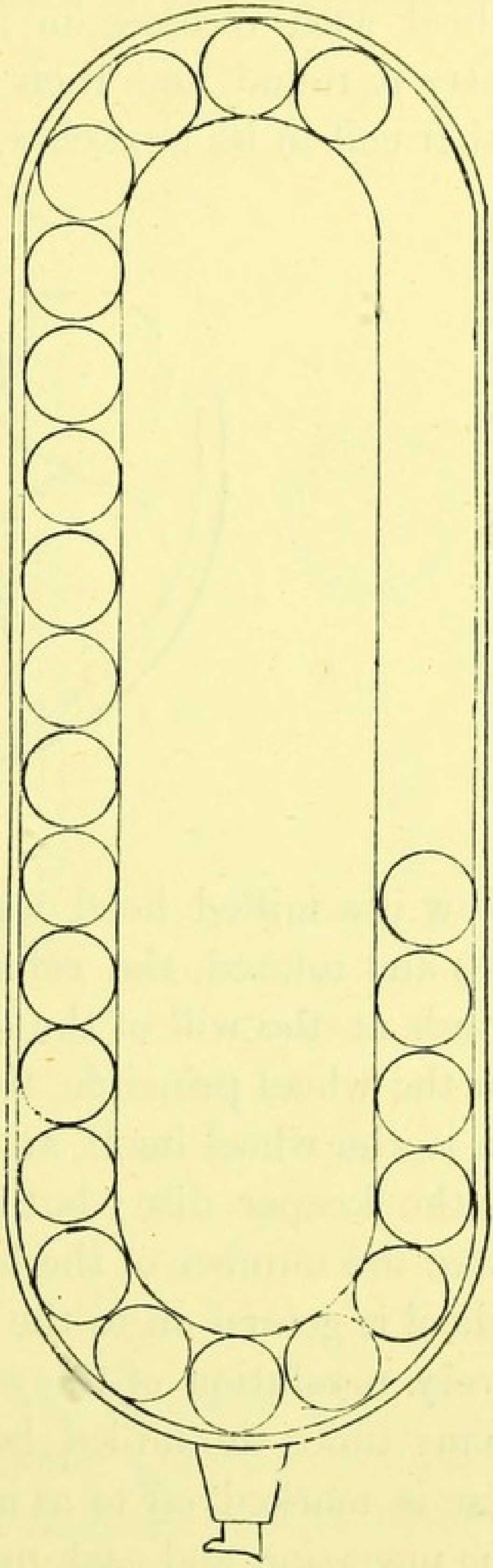


Fig. 37.

The cells being perfect, that is, sliding round without any shake any way in the channel, the next thing to do is to find a method of driving them. This is accomplished by filling to a template or milling out on the lathe a small wheel with recesses in it to grasp each cell in rotation, carry it round, and then send it onwards by bringing another cell in its next claw. Fig. 38 will show it in its place.

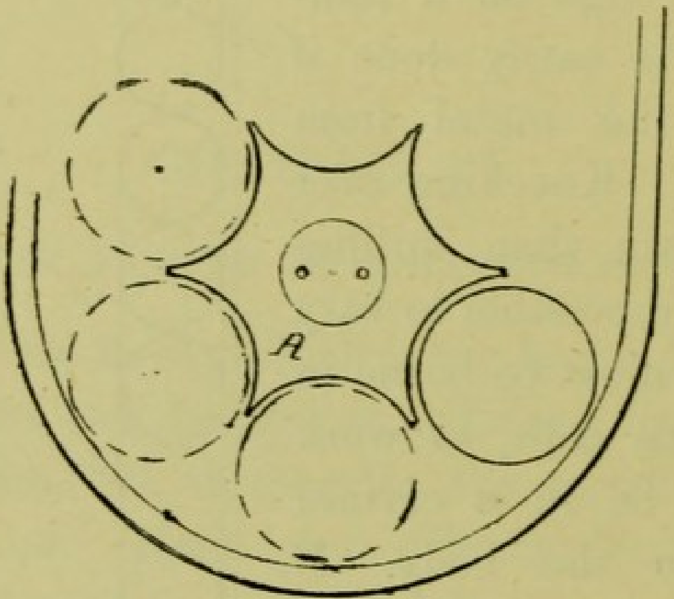


FIG. 38.

Now if a milled head was fastened on the piece A (Fig. 38) and rotated, the cells must wave backwards and forwards at the will of the operator. In all ophthalmoscopes on the wheel principle, the number of the lens is engraved on to the wheel itself, and each shown in an aperture cut in the keeper disc; but in this case it is not practical to have the number of the lens on the cell itself, so a toothed wheel is geared on to the milled head that revolves once to every revolution of the whole of the discs, no matter how many times the milled head itself revolves. This register disc is marked off to as many spaces as there are lenses in the magazine, and each number engraved on the space provided for it. This disc is covered with a thin shield of metal that has a perforation that only allows the number of the lens to be shown that is central with the eye-hole (see Fig. 39). Each of the cells that is to have a lens in

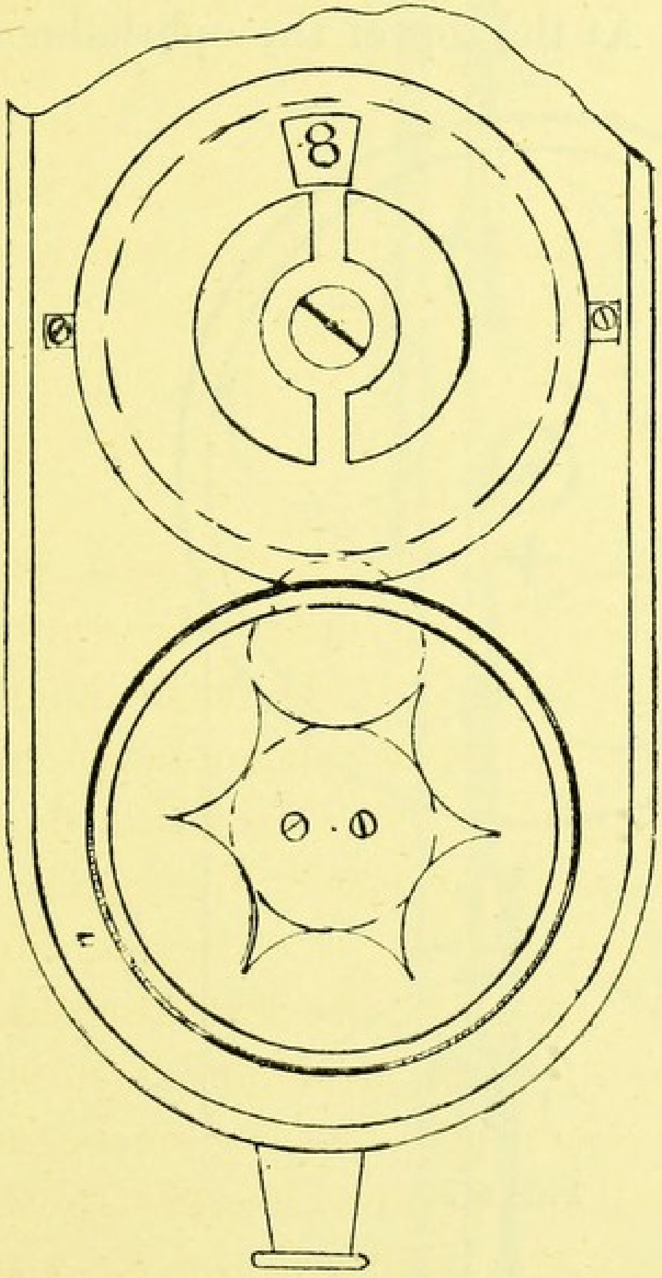


FIG. 39.

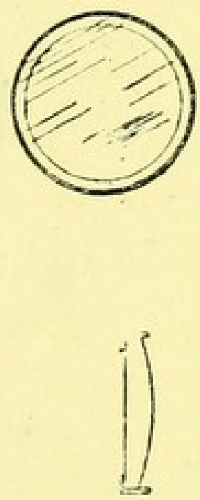


FIG. 40.

is either stamped or turned to the shape of Fig. 40, so that the lens rests on a shoulder, and the eye-hole of the ophthalmoscope being rather smaller than the diameter of the lens, even if they should become uncemented and loose in the cell, it is impossible for them to be lost. Each cell has its own number marked on, so it is a very easy matter to get the cells in their proper order. Once in and the top plate screwed down, it is almost impossible for them to get damaged. At the top of the ophthalmoscope

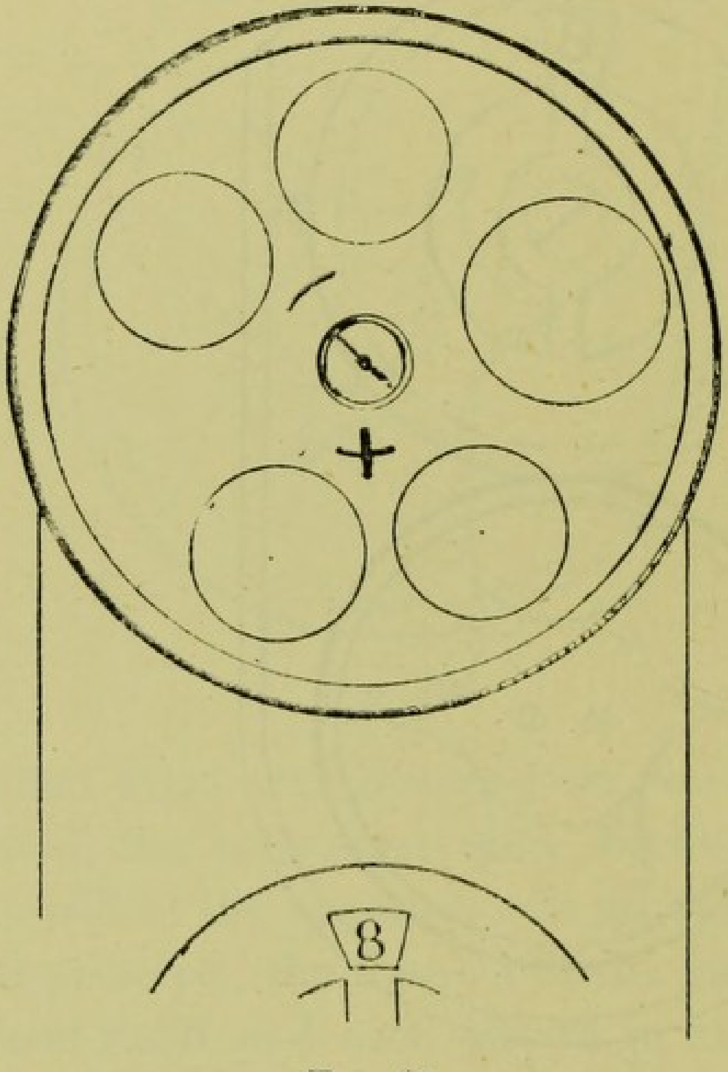


Fig. 41.

is an extra disc, with four additional lenses, which immensely increase the number by containing four lenses of different strengths. The magazine, say, contains 24 convex lenses. Now, if the disc of Fig. 41 contains a concave lens of rather higher power than the highest convex lens in the magazine, and is placed before the eye-hole, you can

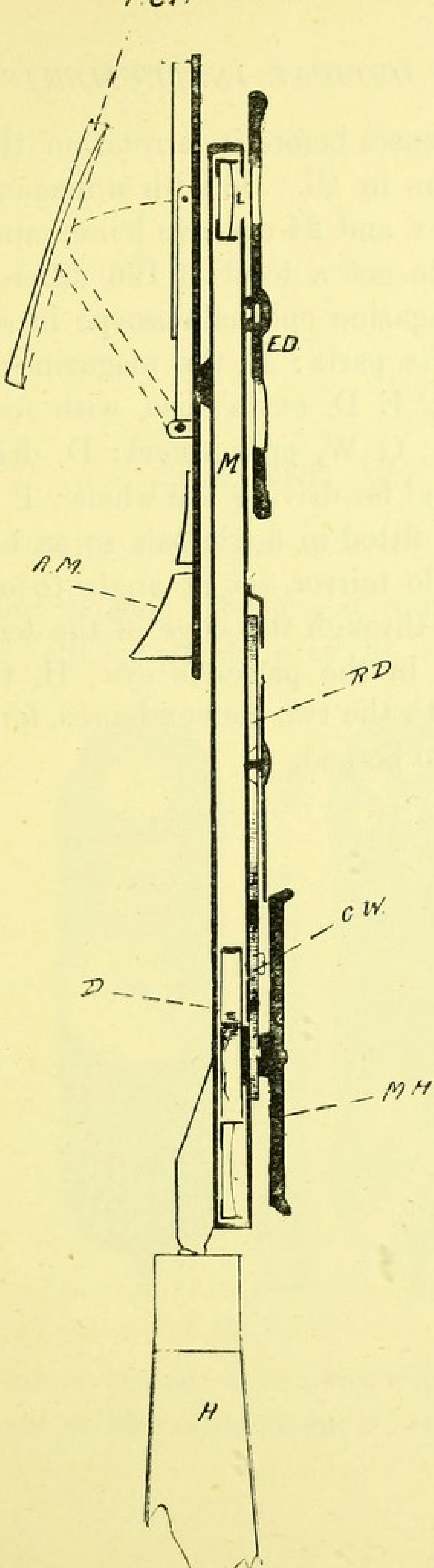


FIG. 42.

bring the various lenses before it in rotation, thus getting a series of 40 powers in all. So with a magazine instrument with 24 convex and 24 concave lenses, and the extra disc, it is possible to get a total of 196 different powers. Fig. 42 shows a magazine ophthalmoscope in section, and the following are the parts: M, the magazine; L, lens in centre of eye-hole; E D, extra disc, with four powers; R D, register discs; G W, gear wheel; D, driving disc; M H, the milled head for driving the whole; P C M, plane and concave mirror, fitted in a gimbals so as to be easily changed; A M, angle mirror, set at angle to obviate the necessity of looking through the edge of the lenses whilst reflecting the light in the patient's eye; H, the handle. This instrument, with the two convex lenses, forms one of the most complete to be had.

CHAPTER VII

VARIOUS FORMS OF OPHTHALMOSCOPES

WITH the Morton, the registering was effected by gearing the register wheel on to the driving milled head;

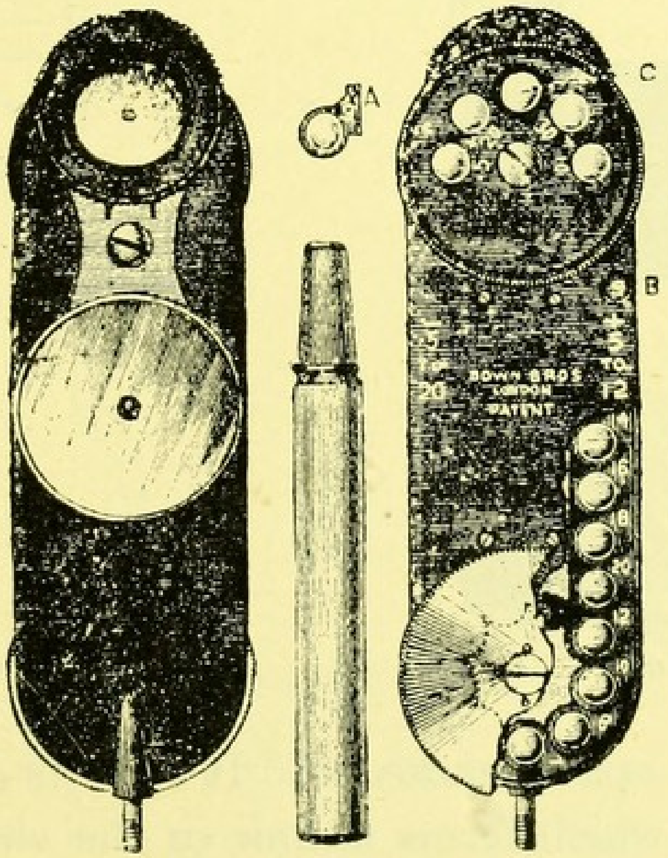


FIG. 43.

but a later improvement does away with this arrangement. The cells are so formed that each has a lug on the side that can have the number of the lens engraved on it, and by an opening in the case each is read in its turn.

DOWNS' OPHTHALMOSCOPE.—The Fig. 43, which is Down Bros.' patent, represents an improvement on the well-

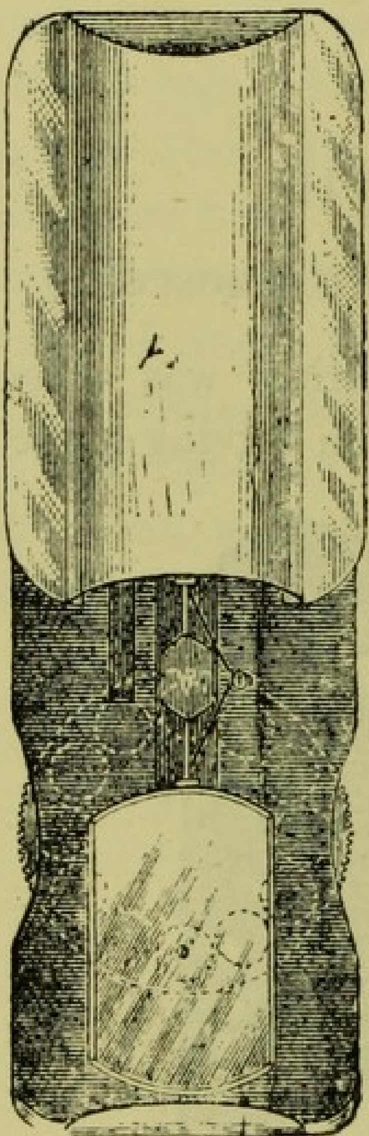


FIG. 44.

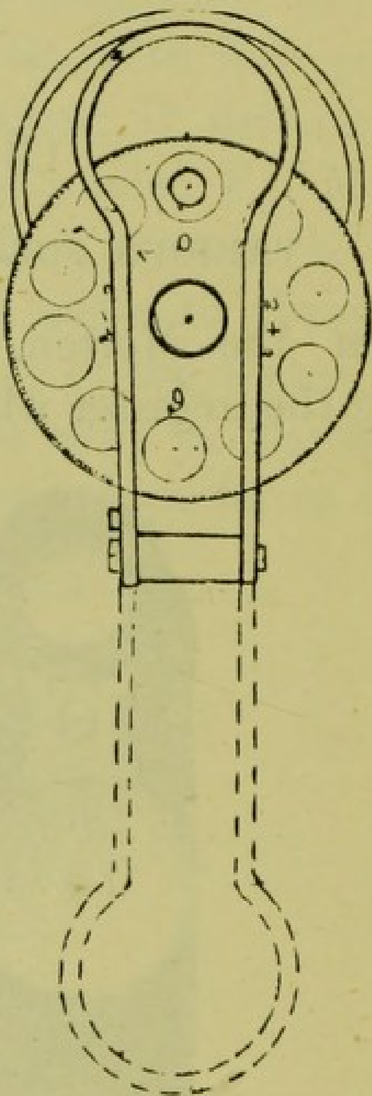


FIG. 45.

known Morton ophthalmoscope. It consists of a new form of lens-holder, which forms a link in the chain of lenses, and answers the double purpose of holding a lens and indicating the power of a lens. This is effected by a number engraved on the lug attached to the lens-holder, A, Fig. 43. This wing does not at all impede the passage of the chain of lenses along the trough or link-race, and it is impossible for the order in which the chain travels to become by any means disarranged. The number engraved

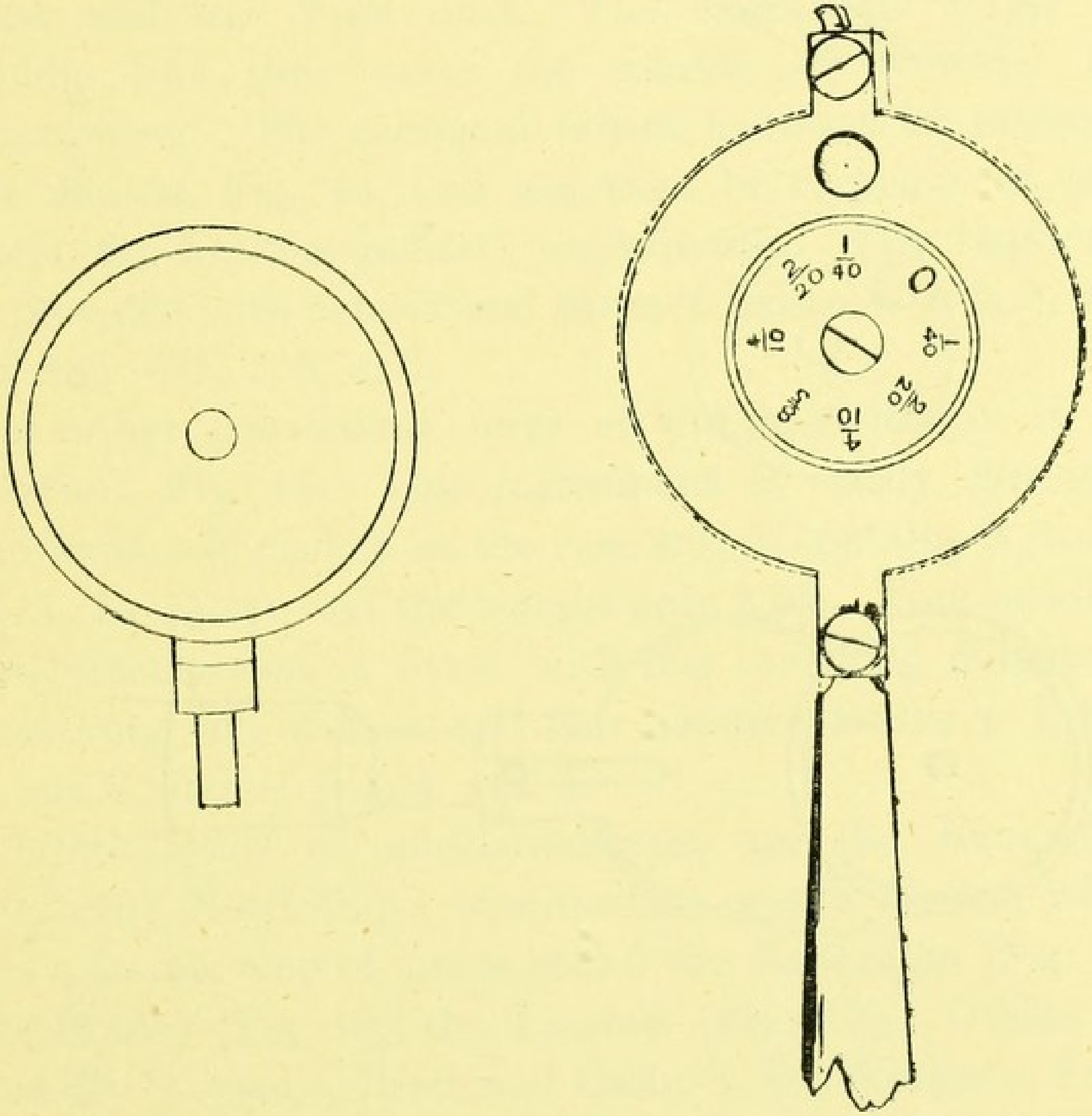


Fig. 46.

on the wing is shown at the sight-hole B, and represents the power of the lens appearing at the sight-hole C, thus dispensing with the complicated arrangement of a time-wheel, used to indicate the power of the lenses in the older form of the ophthalmoscope.

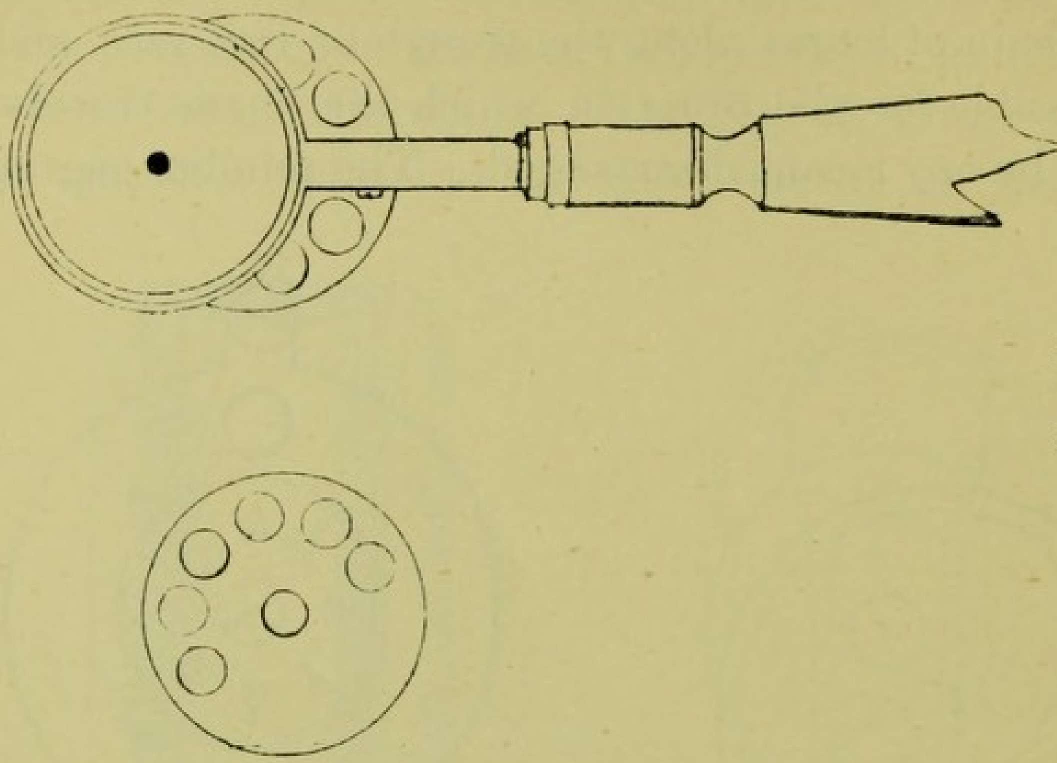


Fig. 48.

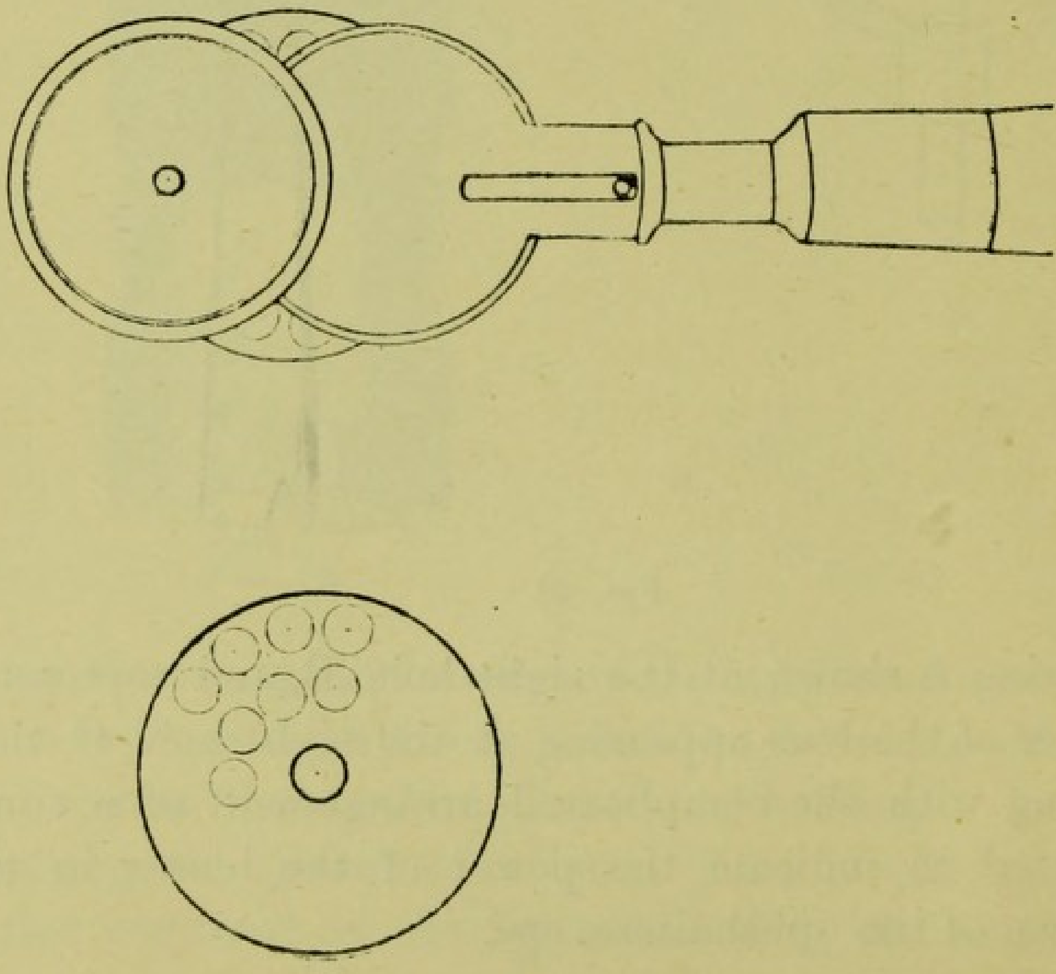


Fig. 47.

Another improved ophthalmoscope has been designed, with the object of at once forming a portable and efficient instrument, and one inseparable from its case, thereby minimizing the risk of breakage, and keeping the lenses clear and free from dust. The case itself forms the handle, and thus saves the trouble of screwing and unscrewing. The sectional mirror is raised by means of the button, Fig. 44, and can then be turned so as to be useful for direct or indirect examination. The diaphragm is provided with convex and concave lenses + 1, 2, 3, 4, 9, 20, and – 1, 2, 3, 4, 6.

Another convenient form of ophthalmoscope is the Oldham, Fig. 45. This instrument is easily carried in the waistcoat pocket, as the case which contains it is only $2\frac{1}{4}$ in. by $1\frac{1}{2}$ in., and the weight only 2 oz. This excellent little instrument is fitted with one revolving diaphragm containing five convex and four concave lenses + 1, 2, 3, 4, and 6, and – 1, 2, 4, and 8.

Other forms of ophthalmoscopes are the Baumeister (Fig. 46), Nettleship's modification of the Gower, which has a double ring of lenses round the diaphragm (Fig. 47), the Brailey (Fig. 48), the Landott (Fig. 49). Others are Bader's, Cowper's, Brudenell Carter's, De Wecker's, Fox's, Gower's, Lang's, etc., each instrument excellent in its construction.

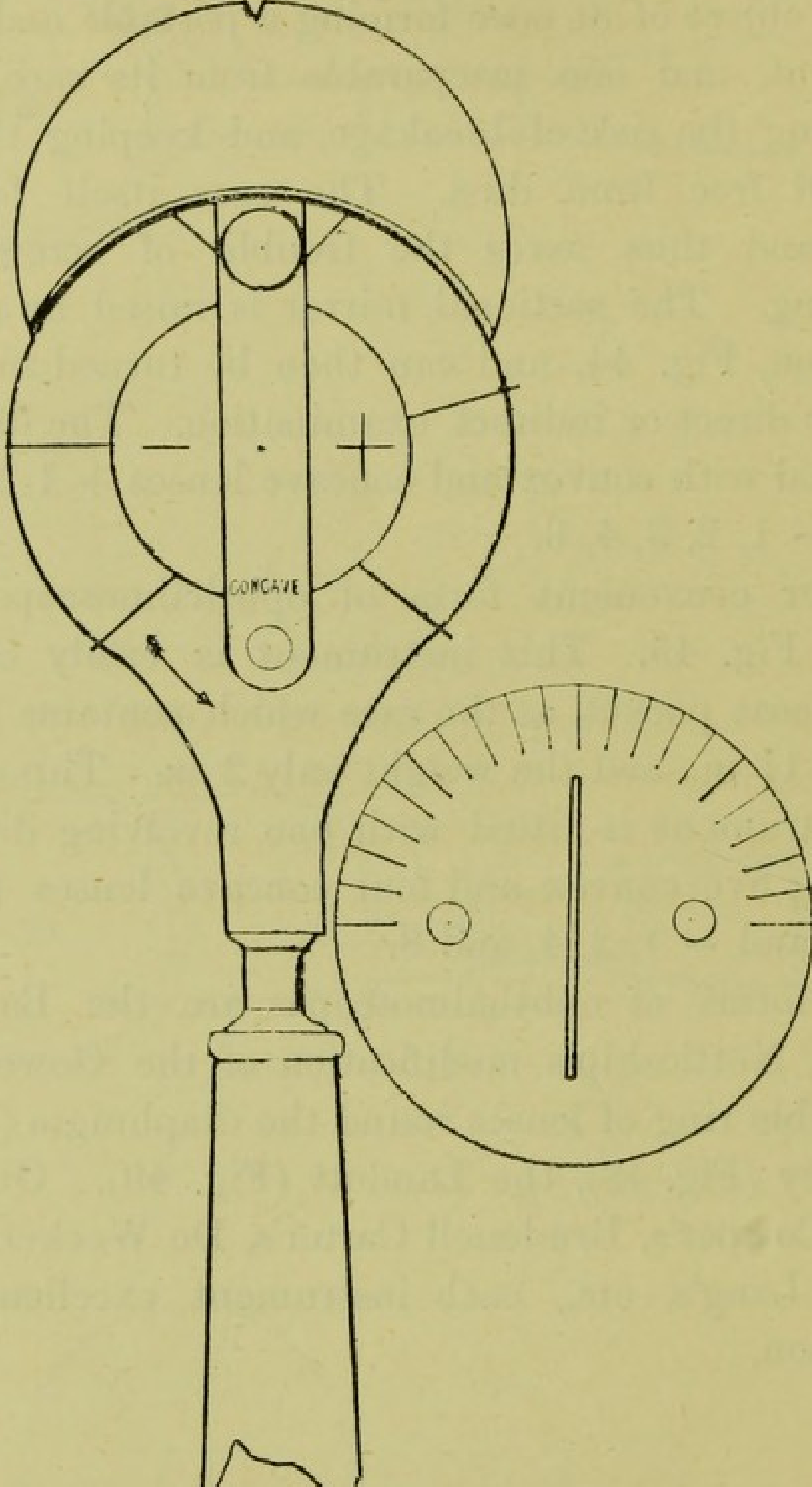


FIG. 49.

CHAPTER VIII

RETINOSCOPY

In examination by plane or concave mirrors, these mirrors for retinoscopy certainly come under the head of an optical instrument; only I should not have described their use but for some letters received asking for information from those who seem to take an interest in these little-known instruments. Mr. Nettleship says, in his valuable work, *Diseases of the Eye,* "Retinoscopy is a valuable means of objectively determining the quantity of any error of refraction, and, as it is more easily learnt, and on the whole more accurate than estimation by the direct method, it has, in the hands of many of our students and assistants, almost displaced the latter method during the last four or five years as a preliminary to testing the patient with trial lenses. For the quick discovery of a very slight astigmatism, and of the direction of the chief meridian in astigmatism of all degrees, retinoscopy probably excels all other methods. Retinoscopy, however, carries with it none of the collateral advantages afforded by a thorough training in the more difficult 'direct method,' for in retinoscopy we see nothing, or think nothing, of the condition of the fundus of the eye. Accurate retinoscopy is not quicker than measurement by this direct method; indeed, with a good instrument, the latter method certainly has the advantage in rapidity. I think there is reason to fear that the free use of retinoscopy by students before they have mastered the more difficult 'direct method' may tend to lower the present high quality of English ophthalmic work."

By examination with mirrors for retinoscopy the refraction is determined by noticing the direction of movements of the light thrown on to the retina by the mirror where the latter is rotated. The degree of error of refraction is measured by the lens, which, placed close to the patient's eye in a case of ametropia, renders the movement and other characters of the illumination the same as in emmetropia. The test is most accurate. When used at a great distance from the patient in practice, a distance of between three and four inches is chosen. The observer, seated in front of the patient, throws the light from an ophthalmoscopic mirror into the pupil of the eye to be examined. He will then see the area of the pupil illuminated, and on slightly rotating the mirror, will notice a movement in this lighted area, which movement will have a direction either the same as, or opposite to, that in which the mirror is turned. The lighted area is bordered by a dark shadow, and it is to the edge of this shadow that attention must be directed.

Retinoscopy may be practised with a plane or concave mirror. With the latter the shadow moves against the mirror in emmetropia, hypermetropia, and low myopia; and with the mirror in myopia of more than 1 D. With the former this is entirely reversed. The light should be thrown as nearly as possible in the direction of the visual axis, and the lamp should be placed immediately over the patient's head.

In Fig. 50, with a concave mirror of about 22 c.m. focus, the mirror M forms an inverted image, 1, of the light, L, at its principal focus, and 1 becomes the source of light for the eye E. A second image of 1 again inverted is formed at 1′ on the retina of E. If the far point of E be at 1, this retinal image 1′ will be clear and distinct; but in every other case it will be more or less out of focus and indistinct. On rotating M to M′, 1 will move to 1^2, and 1′ to 1^2, and these movements (of 1 and 1′) will occur, no matter what the refraction of E may be. The observer placed behind M sees an image of 1′ formed in the same way as the image of the fundus seen by the direct method, and, therefore, either inverted or real, or erect and virtual, according as the refraction of the eye is myopic or hypermetropic. If the observer's eye be accurately adapted for this image of 1′, he will indeed see not only the light and shadow, but also the retinal vessels. If E be myopic, Fig. 51, the image of 1′ is real and inverted and formed at 1″, the far point of E. On rotating the mirror, 1′ will move to 1^2, and 1″ will move to $1''^2$. If the eye be hypermetropic (Fig. 52) or emmetropic, rays reflected from its retina leave the eye divergent or parallel, and are not brought to a focus after emerging: the observer therefore sees a virtual image erect at 1″, the virtual focus of 1, and

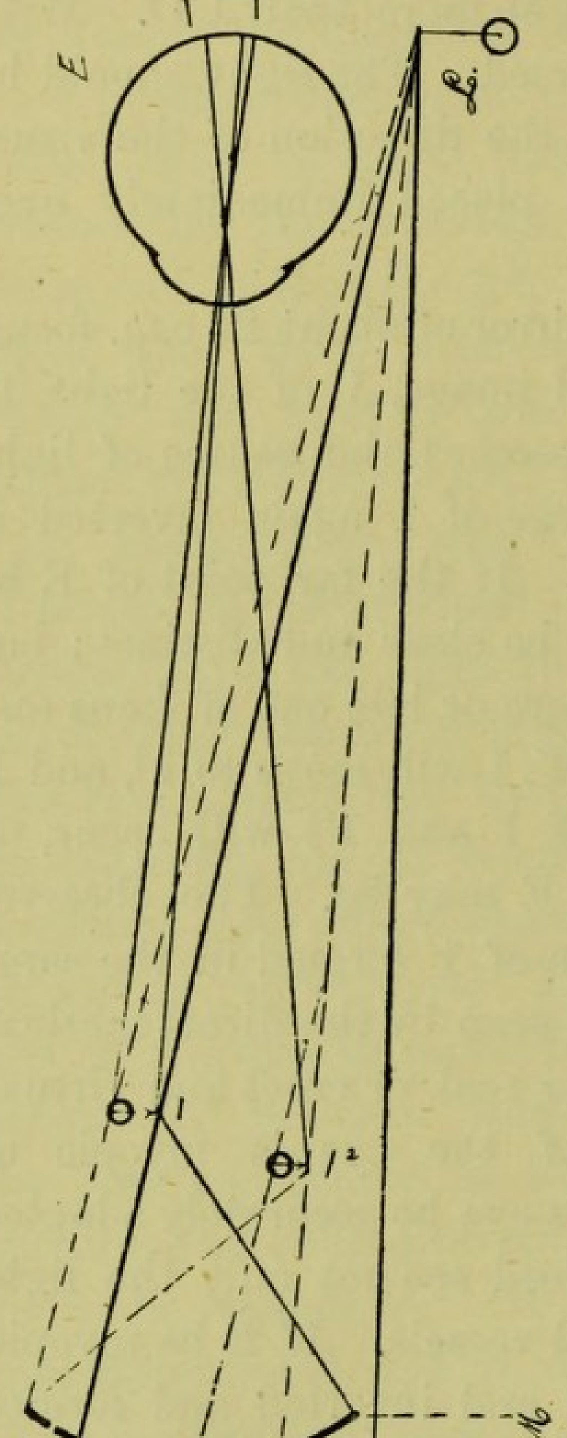


Fig. 50.

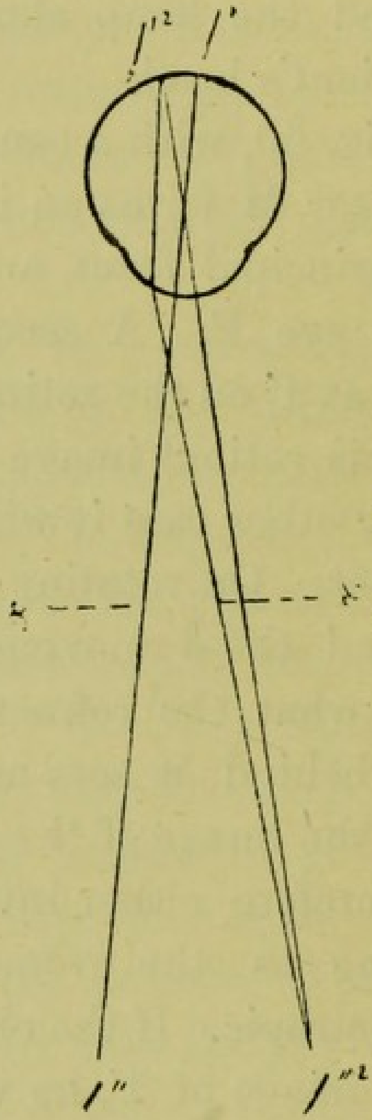


Fig. 51.

sees its movements exactly as they occur, against the movements of the mirror.

The above statement for myopia is true only if the observer be beyond the far point of the observed eye. In myopia of 1 D the rays, returning from the patient's eye,

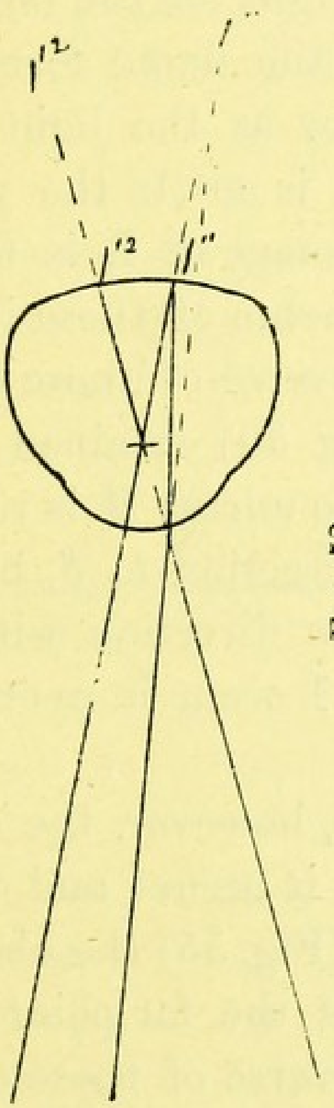


Fig. 52.

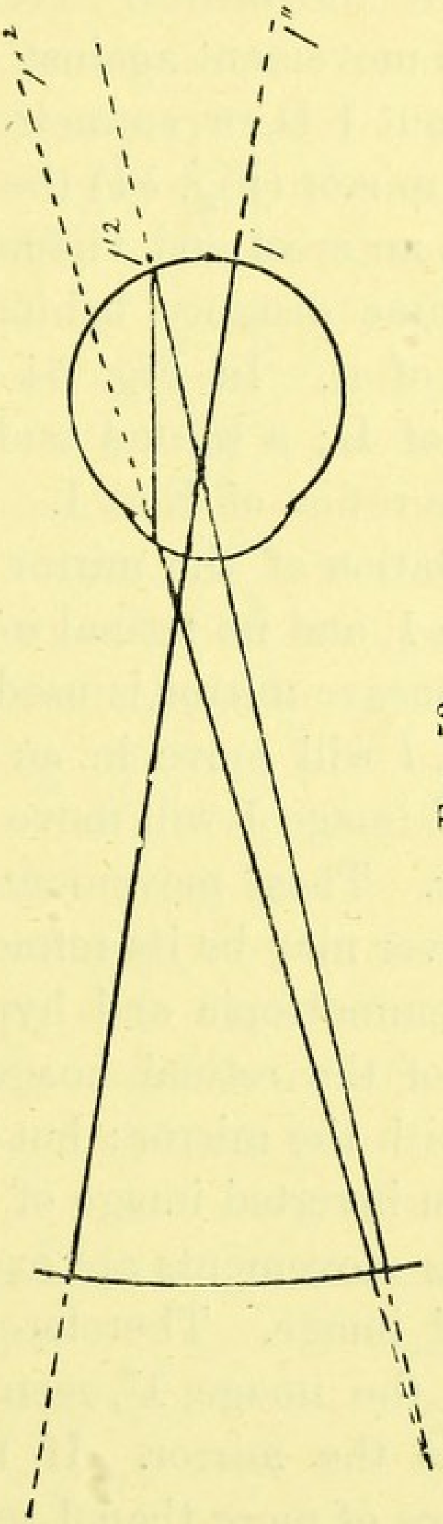


Fig. 53.

are focussed at a distance of one mètre, and if the observer intercept these rays before they meet Fig. 53, he will refer them towards 1″ and 1″2, and obtain an erect, virtual but unfocussed image of 1′, the movements of which will be the same as those in hypermetropia or emmetropia against the mirror. Hence at a distance of about one mètre movement against the mirror may indicate myopia of about 1 D, or emmetropia, or hypermetropia. With a plain mirror (Fig. 54) the source of light for the observed eye is an erect and virtual image of the flame formed at the same distance behind the mirror as the light is in front of it. In Fig. 54 this image is at L, the virtual focus of L; a second and inverted image of L is formed on the retina of E at 1. The movements of these images on rotation of the mirror are the reverse of those of the image 1, and its retinal image 1″ (Fig 50) obtained when the concave mirror is used. When the mirror M is rotated to M′, *l* will move in an opposite direction to *l*′, but its retinal image 1 will move to 1′ in the direction with the mirror. These movements of L and 1 occur in every eye, whatever may be its refraction.

In emmetropia and hypermetropia, however, the movement of the retinal image is seen as it occurs, and therefore with the mirror; but in myopia (Fig. 55) the observer sees an inverted image of 1 formed at the far point of E, and its movements are exactly the reverse of those of the retinal image. Therefore, on rotating M to M′, 1 moves to 1′, the image, 1″, seen by the observer, moves to $1'^2$ against the mirror. If the plane mirror be used at a distance of more than 1 mètre, a movement of the shadow with the mirror will occur with myopia of 1 D or less, but if the observer be about 2 mètres, or 7 ft., away, the movement against the mirror will be obtained, unless the

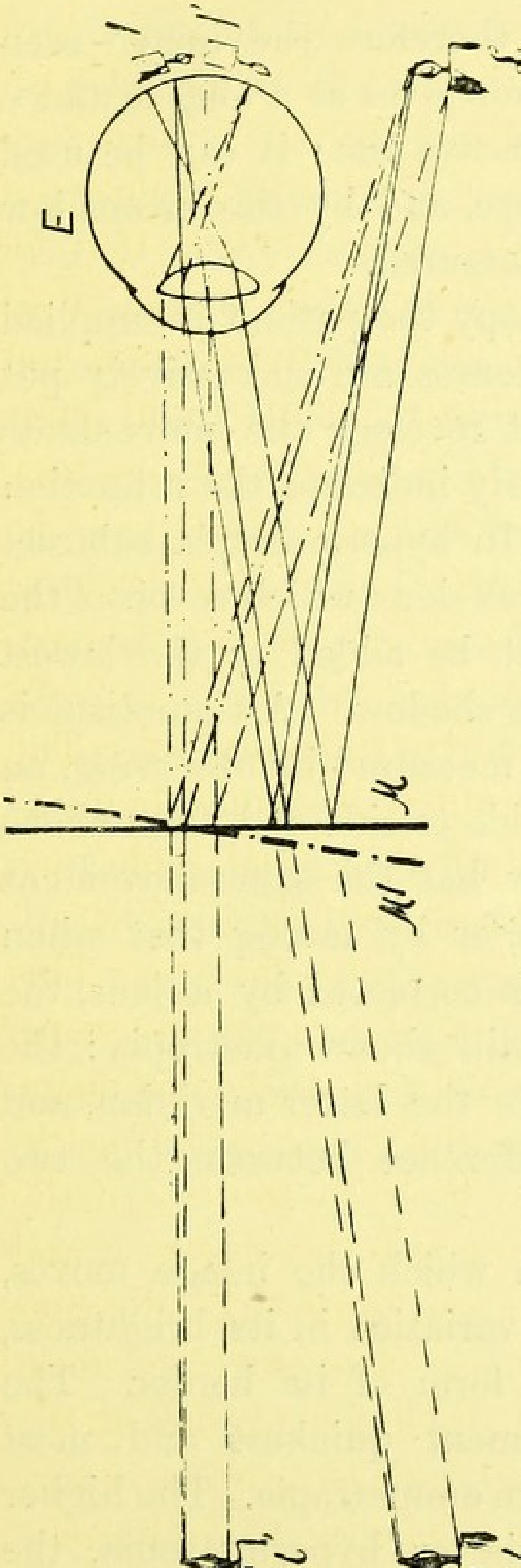


FIG. 54.

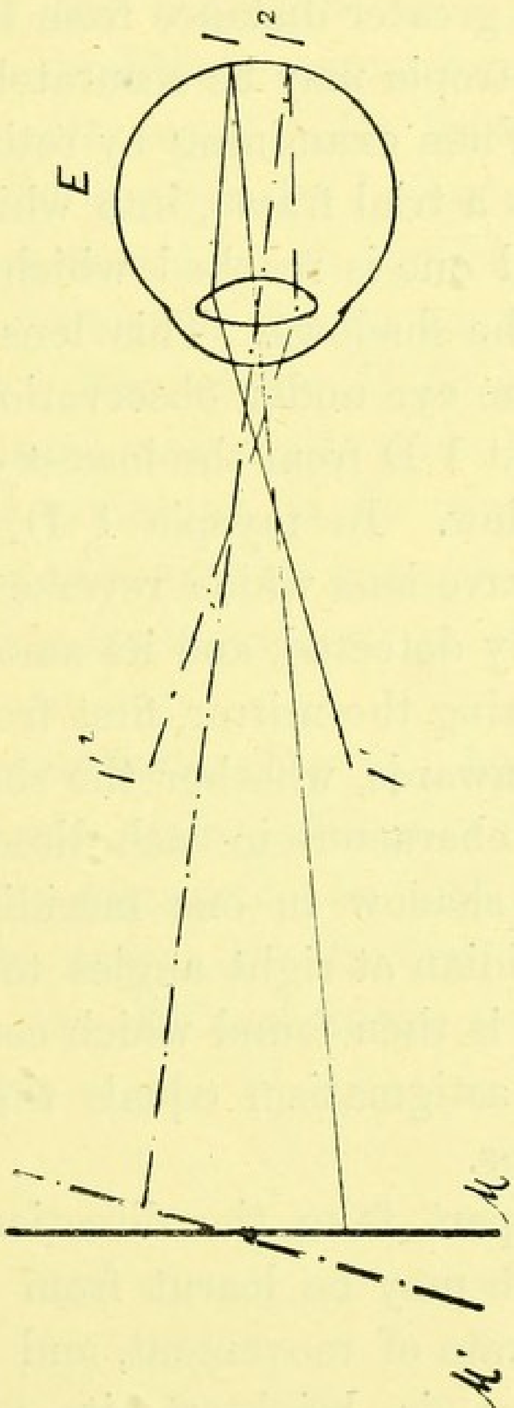


FIG. 55.

myopia be less than 5 D, and therefore the image seen is at 2 mètres. The plane mirror gives at a long distance a better illumination than a concave one; it can be used at a greater distance from the eye, and by this means low ametropia may be accurately measured.

When examining by retinoscopy the patient is supplied with a trial frame, into which lenses are successively put until one is reached which just reverses the movements of the shadows. This lens nearly indicates the refraction of the eye under observation. In hypermetropia subtract about 1 D from the lowest convex lens which reverses the shadow. In myopia 1 D must be added to the lowest concave lens which reverses the shadow. Astigmatism is easily detected, and its amount measured by observing, on rotating the mirror, first from side to side and from above downwards, whether the shadow has the same movement and characters in each direction, or by noting that when the shadow in one meridian is corrected by a lens, the meridian at right angles to it still shows ametropia: the lens is then found which corrects the latter meridian, and the astigmatism equals the difference between the two lenses.

Apart from the direction in which the image moves, much may be learnt from the variation in its brightness, its rate of movement, and the form of its border. The image is brightest, its movement quickest and most extensive in very low myopia or in emmetropia. The higher the ametropia, whether myopia or hypermetropia, the duller is the illumination, the slower and less extensive its movement, and the more ill-defined its border. The brightness of the image depends on how clearly 1, Fig. 50, is focussed on the retina. The more accurately 1′ is an image of 1, the brighter and larger will 1″ (Fig. 51) be, and as the flame is rectangular, the borders of the image will be nearly straight. These conditions occur when the eye is exactly adapted for the distance of 1, for instance, in myopia of 1 D or less. If the myopia be higher than 1 D, 1 will be out of focus, and, therefore, be spread over a large retinal area, and being formed by the same number of rays, it will be less bright. The image 1″ (Fig. 51) will be correspondingly diffused and dull, and being formed nearer to the eye being examined, as, for example, at x, it will move only from x to x' in the same time as 1″ takes in moving to $1''^2$; hence its movement is slower and less extensive.

The same is true in hypermetropia (Fig. 52), because the higher the hypermetropia, the more diffused is 1′ and the nearer is 1″ to the eye being examined. In both cases, high myopia and high hypermetropia, the border of the shadow is crescentric, because the diffused image forms a nearly round area on the retina.

CHAPTER IX

SPECTACLES AND THEIR SELECTION

SPECTACLES and their kindred, with the legion of shapes, sizes, and questionable capabilities, are sufficiently well known as to have merely a passing glance; but being the best known of any optical instrument, and with the gigantic amount of benefit they confer on mankind, we cannot let them pass without a brief notice at least, if they do not warrant the description their more complicated relations require. The different forms of lenses have been partly explained; it is only necessary to give a description of the mechanical contrivances for holding the same in position. A good frame is as vital to the wearer as the lenses, and certainly great care should be taken to insure their suitability to the case required.

MEASUREMENT FOR SPECTACLES.—To obtain measurement from pupil to pupil, the prescriber is seated opposite the patient, in a good light, the latter looking straight before him at a fixed distant point. A measuring-rule is rested on the nose of the patient, the prescriber being as far away as he can comfortably reach. The zero of the scale being placed opposite the centre of the left pupil, the centre of the other may be marked with the nail (Fig 56). This distance does not vary much from $2\frac{3}{8}$ in.

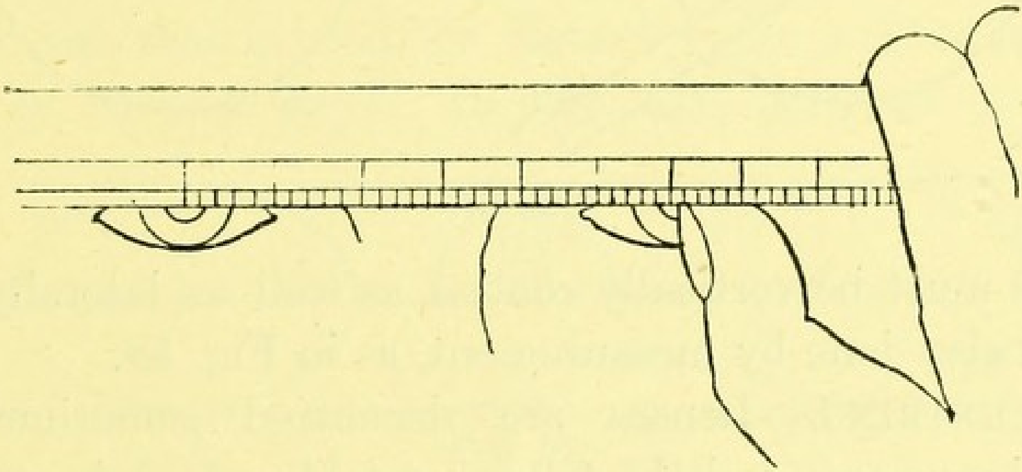


FIG. 56.

An allowance must be made, as the prescriber's eyes are about 2 ft. away, and the rule is about $\frac{1}{2}$ in. The marks upon the rule, though apparently opposite the pupils, are really a little within their actual centres. If two millimètres are added to the distance previously marked, it will be approximately perfect.

THE PUPIL LOCALIZER.—If greater perfection should be needed, a pupil localizer can be slipped in the recesses of the trial frame, which has a graduated bar for measurement of interpupillary distance. This pupil localizer consists of a semicircle of metal, with a pointer some distance in front of it (see Fig. 57). The gaze of the observed and the observing eye being directed to each other's pupils, the two sights of the implement are brought into line between them. The same is gone through with the other eye, and the distance of the second pupil from the median of the face, as registered by the trial frame, is added to that of the first to obtain the distance. The

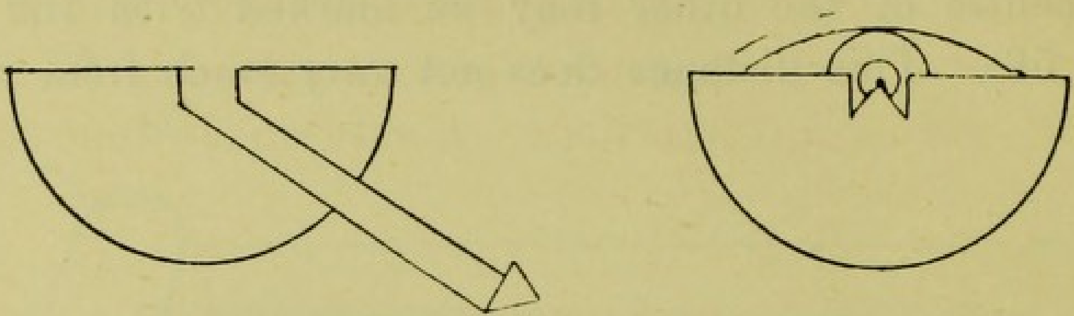


FIG. 57.

frames must be vertically central as well as laterally, and this is also done by measurement, as in Fig. 58.

DECENTRING.—Lenses are decentred sometimes for special purposes, and the following table, which is approximately correct, can be relied on, and is equivalent to a given refracting angle, index of refraction being 1·54—

Lens.	1°	2°	3°	4°	5°	6°	8°	10°
1 D.	9·4	18·8	28·3	37·7	47·2	56·5	75·8	95·2
2 ..	4·7	9·4	14·1	18·8	23·6	28·2	37·9	47·6
3 ..	3·1	6·3	9·4	12·6	15·7	18·8	25·3	31·7
4 ..	2·3	4·7	7·1	9·4	11·8	14·1	18·9	28·8
5 ..	1·9	3·8	5·7	7·5	9·4	11·3	15·2	19·0
6 ..	1·6	3·1	4·7	6·3	7·9	9·4	12·6	15·9
7 ..	1·3	2·7	4·0	5·4	6·7	8·1	10·8	13·5
8 ..	1·2	2·3	3·5	4·7	5·9	7·1	9·5	11·9
9 ..	1·0	2·1	3·1	4·2	5·2	6·3	8·4	10·5
10 ..	·9	1·9	2·8	3·8	4·7	5·6	7·6	9·5
11 ..	·9	1·7	2·6	3·5	4·3	5·1	6·9	8·7
12 ..	·8	1·6	2·4	3·1	3·9	4·7	6·3	7·9
13 ..	·7	1·4	2·2	2·9	3·6	4·3	5·8	7·0
14 ..	·7	1·3	2·0	2·7	3·4	4·0	5·4	6·8
15 ..	·6	1·3	1·9	2·5	3·1	3·8	5·1	6·3
16 ..	·6	1·2	1·8	2·4	3·0	3·5	4·7	6·0
17 ..	·6	1·1	1·7	2·2	2·8	3·4	4·5	5·6
18 ..	·5	1·0	1·6	2·1	2·6	3·1	4·2	5·3
19 ..	·5	1·0	1·5	2·0	2·5	3·0	4·0	5·0
20 ..	·5	·9	1·4	1·9	2·4	2·8	3·8	4·8

Bifocal Glasses.—Where glasses of a different focussing power are required for near or distant vision, the trouble of frequently changing them is obviated by bifocal glasses; that is, the lower part of the spectacle eye which is used for near work is made to differ in focus from the upper part that is used for distant vision. This may be done in several ways. In the first patterns each eye

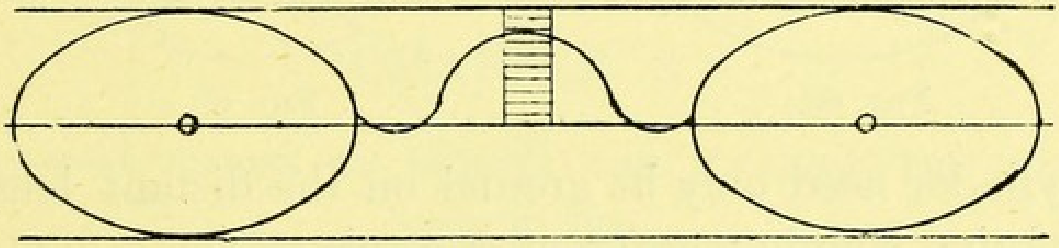


Fig. 58.

contained two half-oval pieces (see Fig. 58), with their straight edges together. This was improved by making the line of conjunction a curved one (Fig. 59), giving

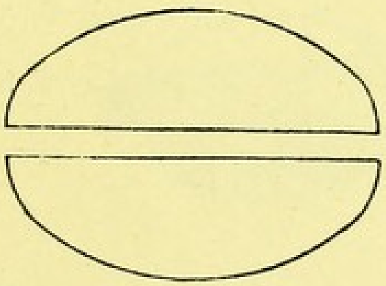


Fig. 58.

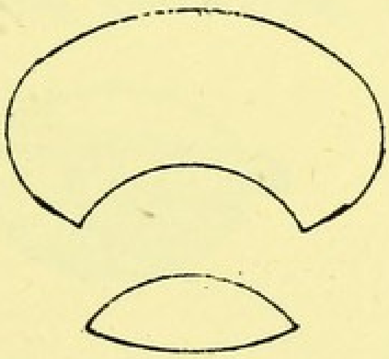


Fig. 59.

greater range of distant vision. They were also made in one piece, called ground bifocals (Fig. 60); but the difficulty of approximately centring the different curves was great, and they generally gave a prismatic effect. The others (Fig. 61) are cemented bifocals, and to the back of the distant glass is cemented a small lens whose power, added to that of the distant lens, equals the strength required for near work. For cylindrical lenses this form is best, as

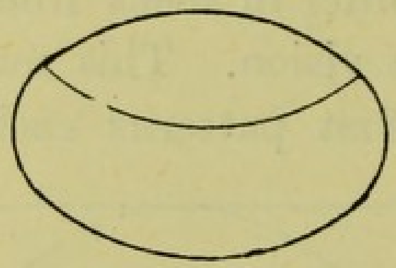


FIG. 60.

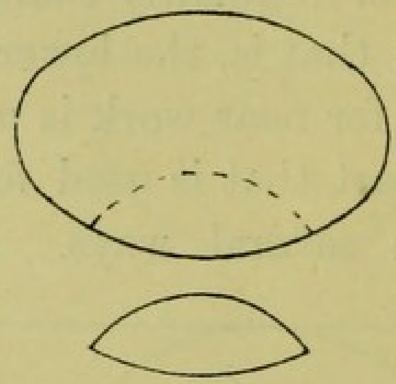


FIG. 61.

the cylinder need only be ground on the distant lens, the other being simply a segment of a sphere.

CHAPTER X

VARIOUS FORMS OF SPECTACLES ILLUSTRATED AND DESCRIBED

THE most perfect vision with spectacles is produced when the eye looks in the direction of the axis of the lens, and imperfection always attends oblique vision through them, which imperfection increases with the obliquity. Persons using spectacles are obliged to turn

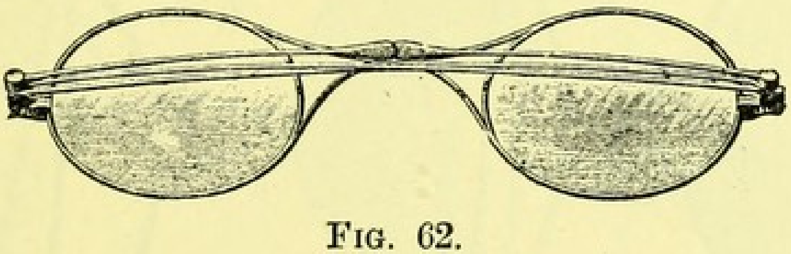


FIG. 62.

the head, whilst people who do not require their assistance merely turn the eye. To diminish this inconvenience, meniscus lenses were introduced instead of the double concave or convex lenses hitherto used. The effect of these lenses, as compared with the double-concave or double-convex, is that objects seen obliquely through them are less distorted, and consequently there is greater freedom of vision by turning the eye without turning the head. These glasses are termed periscopic spectacles.

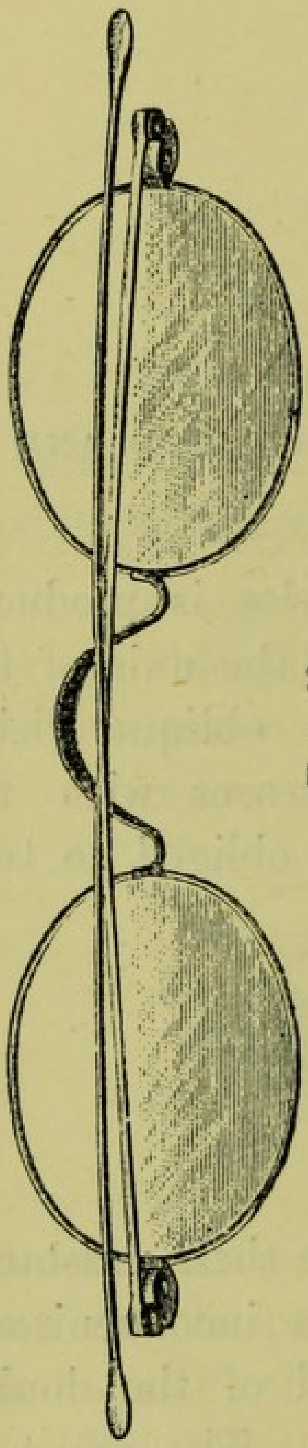


Fig. 63.

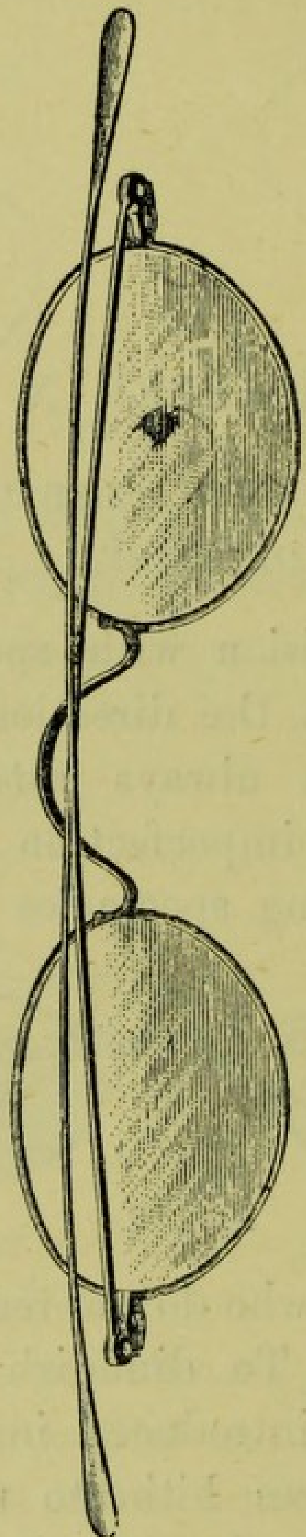


Fig. 64.

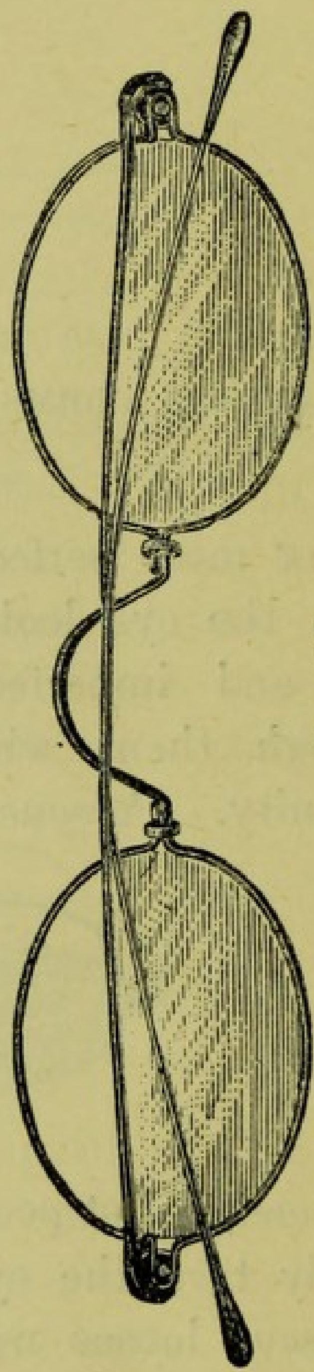
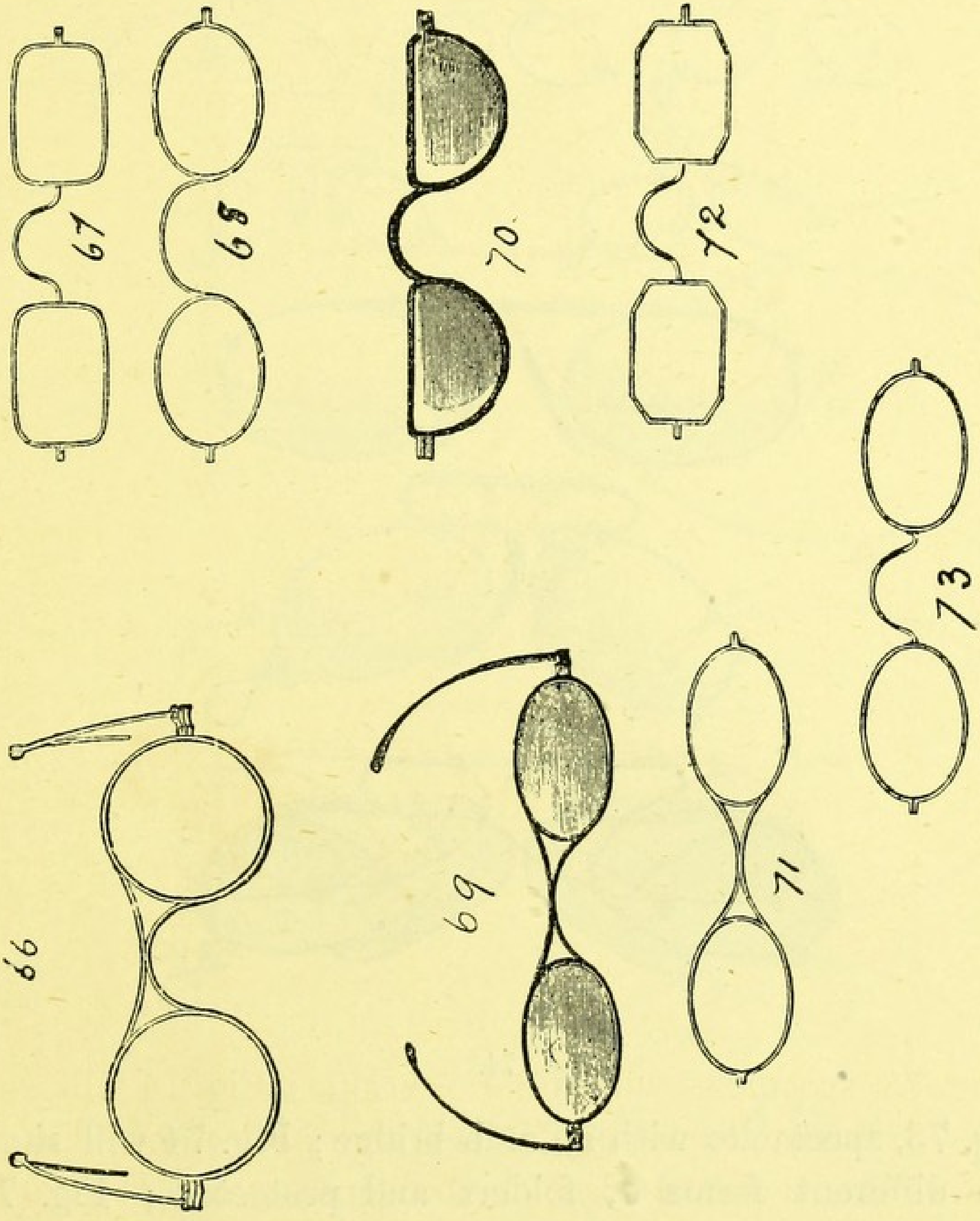


Fig. 65.

Spectacles are various in shapes, but those illustrated will be amply sufficient to show the different forms commonly used. Fig. 62 shows a spectacle frame with turn-pin sides; Fig. 63, spectacles with oval eyes; Fig. 64, pantoscopic eyes; Fig. 65, a frame with twisted joints, no



solder being used in their construction; Fig. 66, spectacles with round eyes; Fig. 67, oblong eyes; Fig. 68, spectacles with crank bridge; Fig. 69, spectacles with a K-bridge; Fig. 70, spectacles with half-moon eyes; Fig. 71, spectacles with a X-bridge; Fig. 72, spectacles with octagonal eyes;

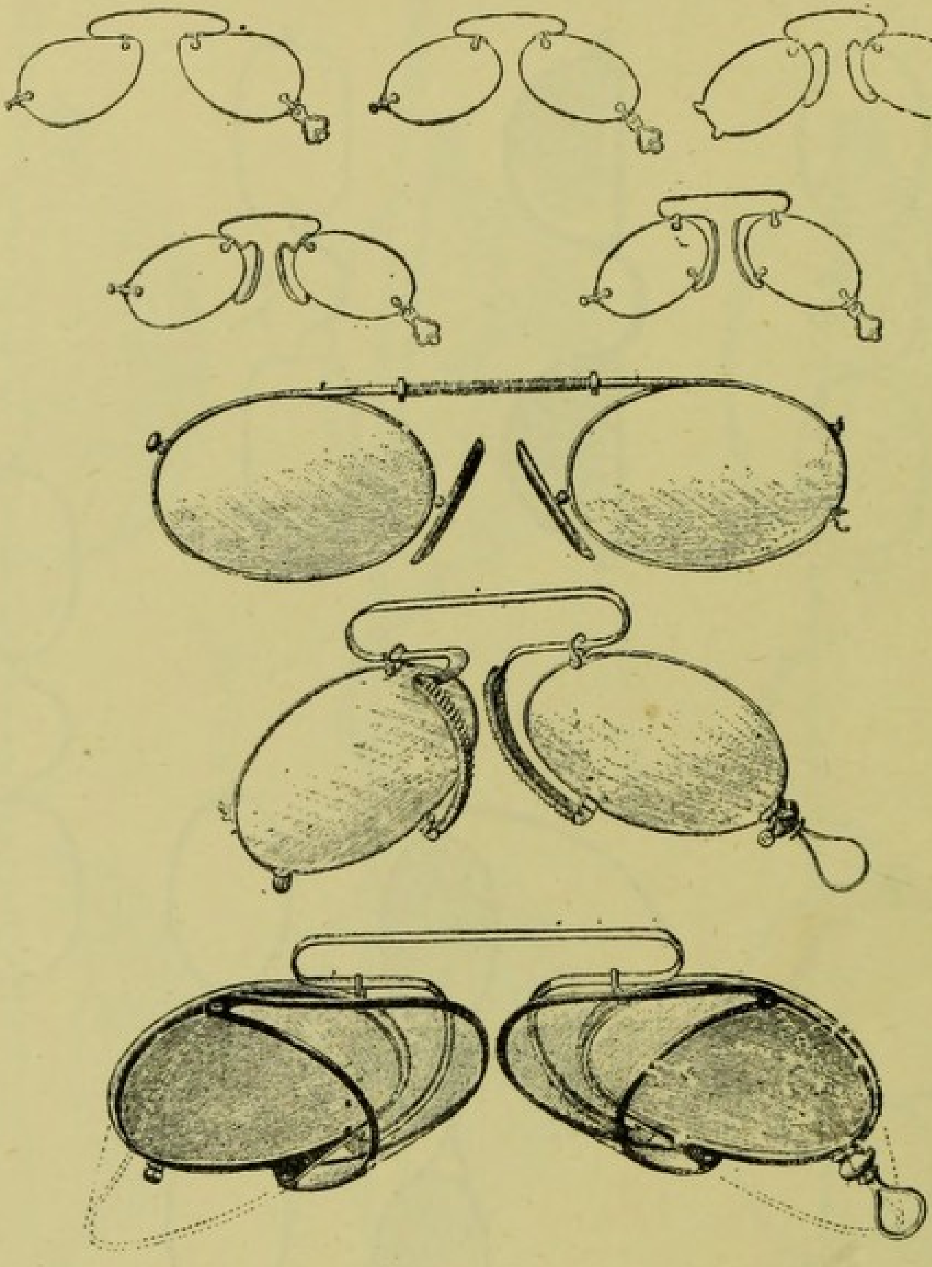


FIG. 74.

Fig. 73, spectacles with an arch bridge; Fig. 74 will show the different forms of folders and protectors; Fig. 75 shows the standard sizes of the lenses; and Fig. 76 the springs, placquets, etc., the frames are built up with.

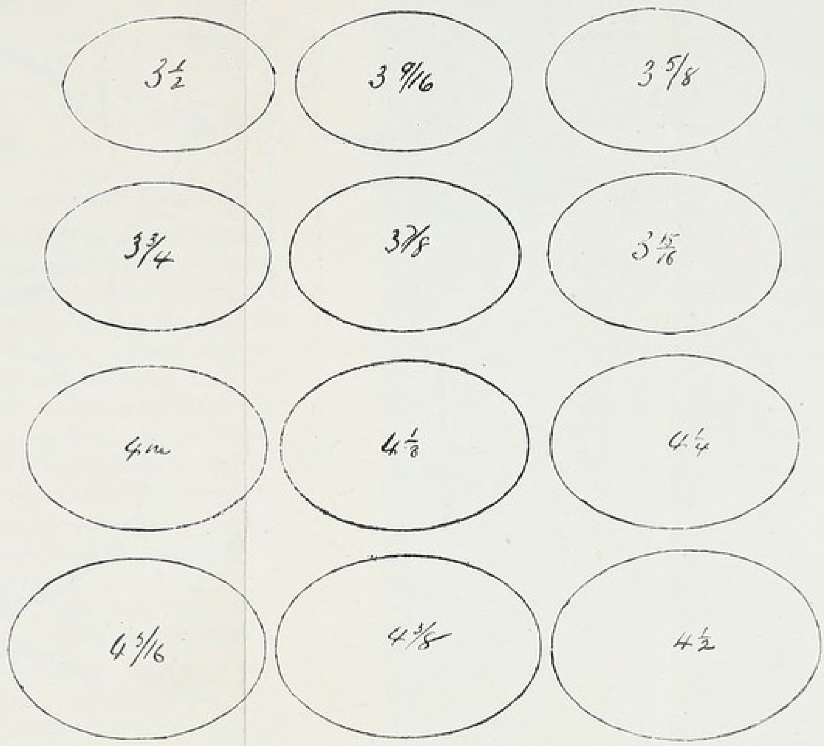


FIG. 75.

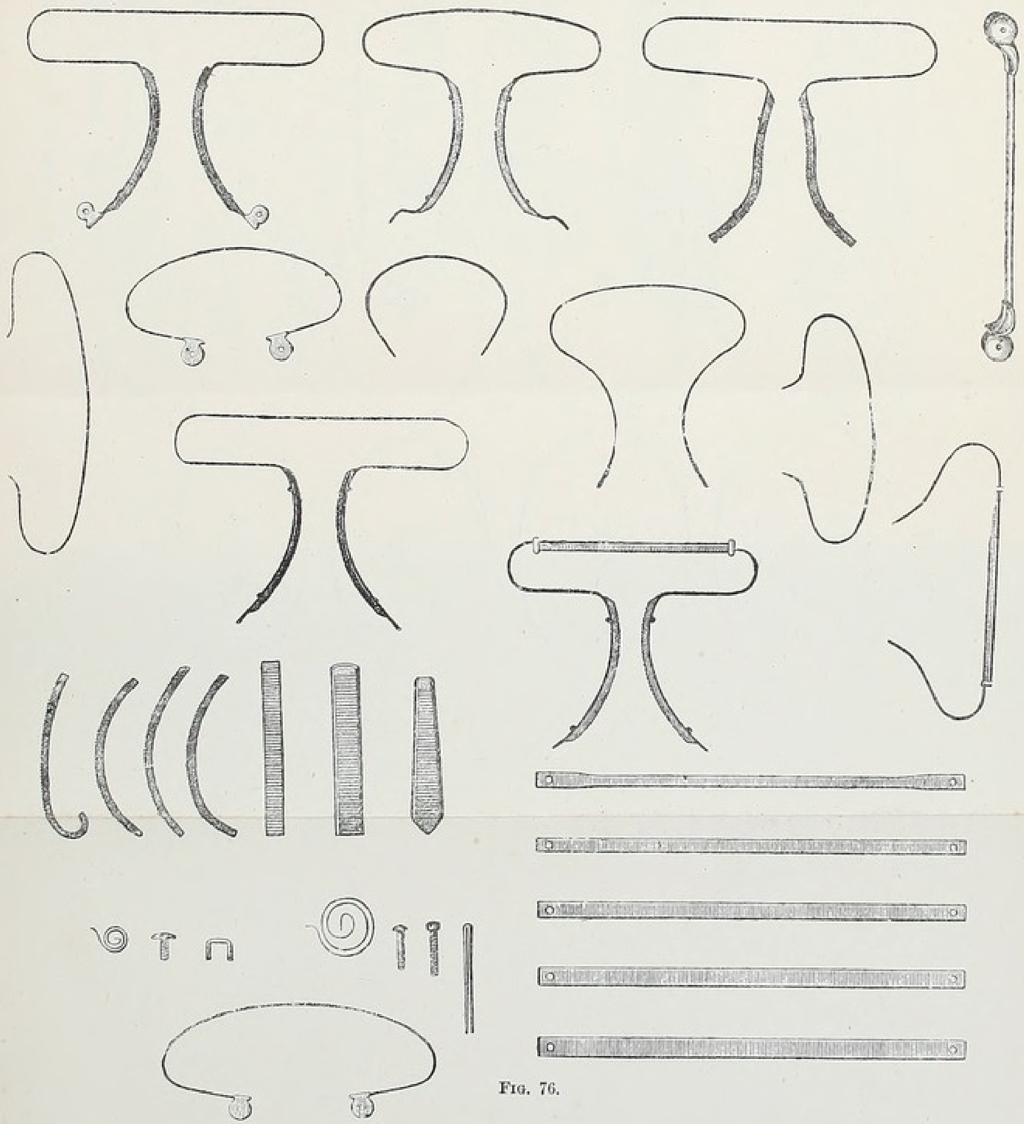


Fig. 76.

CHAPTER XI

STEREOSCOPIC PROJECTION—ANDERTON'S SYSTEM

OPTICAL lanterns and stereoscopes forming the subjects of the next few chapters, a description of the two combined will no doubt be interesting. This method is the invention of Mr. Anderton. In devising his system of stereoscopic projection, the inventor has carefully steered clear of apparatus of a delicate or intricate character, and has aimed at producing the effect without calling on the lantern operator to put forth exceptional care and skill. An ordinary biunial lantern is utilized; the jets are turned on; the two slides forming the stereoscopic pair are placed in position and approximately registered, and, these having received attention, all the demands of the system have been fully met by the manipulator.

Over half a century has passed since Prof. Wheatstone advanced his theory of binocular vision, and proved its truth by the invention of the reflecting stereoscope, and during the fifty odd years that have elapsed since his great discovery many attempts have been made to produce stereoscopic effects by means of pictures projected by optical lanterns. At first sight it does not appear to offer any great difficulties to the adapter; but bringing to bear upon the matter a little consideration, we find the seeming simplicity takes to itself wings and soars out of sight, and difficulties bristle up formidably in its place.

In the stereoscope we have a pair of pictures and a pair of lenses in practically fixed positions, and near to the latter the eyes of the observer must be placed. Move any one of the three and the others must follow. Obviously a lantern stereoscope, constructed on a similar principle, would be a scientific curiosity, and nothing more, and an expensive one to work withal, for a pair of 10 ft. pictures to each observer would be a luxurious form of entertainment. Therefore, to be effective, one pair of projected pictures must serve for any number of persons, irrespective of their position with respect to the screen upon which they are focussed. It will at once be seen that the pictures could not be placed side by side if the above requirements are to be fulfilled, and it is equally clear that the pictures must be superposed.

This being so, we have on our screen two equally bright pictures, and the problem to be solved is to convey one of these pictures to the right eye of each observer, and the other picture to each left eye, and these irrespective of position. Mr. John Anderton has solved the problem by taking advantage of the properties possessed by light when polarized. Light can be obtained in this condition either by absorption, as when passed through a plate of tourmaline by double refraction, by reflection from glass and other substances, and by transmission through a number of plates of thin glass. As the last-named method is the one used by the inventor, both for obtaining polarized light in his lantern, and for analyzing it, we will turn for a brief space from the consideration of the lantern stereoscope to perform a simple experiment.

Taking, say, forty pieces of thin glass, we divide into two parts, and mount each twenty at an angle on a separate piece of short tube or other convenient form of holder. Upon looking through either of these we are conscious that objects appear less bright than before, no other change being apparent. Holding one in the right hand and one in the left, we will again look through them, and we find that if two "bundles" of thin glass be held in the same plane no change is observable. Now if we turn either round even a quarter of a revolution, we find we can see little or nothing through them; turn on through another quarter, and objects are seen as clearly through them as before. We can now turn to our biunial lantern again, and, turning on its bottom jet, focus a slide upon a screen.

If we slip into our objective tube one of our bundles of thin glass the pictures will be on the screen as before, the only apparent difference being that it is not so bright as formerly; in every other particular it is seemingly the same, but appearances are proverbially deceptive, and in the present case we shall see that they are strikingly so, for if we look through our second little bundle we shall find that our screen picture behaves strangely, disappearing and reappearing as the bundle is revolved. To make this quite clear we will hold it in the same plane as is its fellow in the lantern, and upon looking through it we shall see the pictures as clearly as without it. Now we turn it through a quarter of a circle, and find that the picture has practically disappeared; turning on through another quarter it re-appears. Another quarter-revolution accomplished and it again disappears, and when the revolution is completed it has re-appeared. If, instead of turning the bundle held in the hand, we will revolve that in the lantern, we shall find that exactly the same changes will occur. We will go a step farther, and make two more bundles, and place one of these in the top lantern of our biunial, set with its plane at right angles to the bundle in the bottom lantern.

Upon the screen we now have two pictures superposed, and if we look through one of our bundles we find we can see only one of the pictures at a time, and each in turn, as we revolve. To make this quite clear, we place in the bottom lantern a slide of a bear, and in the top lantern an interior view of the House of Commons. Upon looking through the bundle, we shall see one only of the superposed pictures, that of the bear, when the bundle is held in a similar plane to that of the bundle in the top lantern; whilst the interior view of the House of Commons will become visible when the bundle is in a position corresponding to that in the bottom lantern. If we take a bundle in each hand and hold them in the positions indicated, we find that through one the bear will be seen, and through the other the interior will be visible.

If, therefore, we substitute a stereoscopic pair for the two dissimilar slides, we have fulfilled the conditions required to obtain stereoscopic effect, for one picture of the pair falls upon the right eye, and upon the corresponding portion of the retina of the left eye the other picture falls, and these two pictures coalesce in the brain, and the irresistible impression is conveyed to the mind of one picture possessing the attributes of relief and solidity.

I have assumed that the screen used is a suitable one, and it is necessary to state that had we made our experiments with any of those ordinarily used, whether linen, paper, or a whitened wall, no effect could be obtained, for the simple reason that they depolarize the light falling upon them, and the analyzers (bundles) become powerless. The screen devised by the inventor is faced with dead silver leaf, and this material, in addition to answering the purpose, is far before any other for giving a brilliant picture with an ordinary lantern, although it is perhaps not quite so agreeable in colour as those in ordinary use.

The bundles of analyzers are mounted in the form of a miniature opera-glass, and, as they contain no lenses, they need no adjustment, and the instant they are raised to the eyes the blurred pictures, with here and there double outlines, are resolved into one clear and distinctly solid picture. I have said nothing of the difficulties of obtaining a clear and well-defined picture through a bundle (polarizer) consisting of many plates of thin glass; but the result of almost countless experiments is an arrangement that produces a picture of good definition. A similar difficulty arose with respect to the analyzers, and recourse to a pair of Nicol's prisms would have saved the inventor a large amount of experimental labour. There are, however, two formidable objections to the use of Nicol's prisms that could not be overcome or removed. The first is the small angle of view they allow, and the second is the comparatively large cost.

Those who are familiar with the subject of polarized light will naturally imagine that the lantern stereoscopic picture must inevitably be dark and dim, from the large amount of light reflected by the polarizers; and were an ordinary screen used, the picture would undoubtedly suffer severely from want of brightness; but in the dead silver-faced screen we have the best irregular reflecting surface known, and, therefore, the loss of light occasioned by the polarizers is practically the only loss.

I stated at the beginning of this chapter that the two slides forming the stereoscopic pair need only be approximately registered upon the screen. It should be mentioned that as the pictures have necessarily been taken from a different point of view, they are not identical, and therefore perfect registration is impossible. Fortunately, this is in no sense a drawback, for the stereoscopic effect is obtainable if the pictures are purposely separated to some 6 in. or so from one another. A peculiar effect is seen when the observer moves across before the screen, as the objects in the foreground appear to follow him in whichever direction he moves. The polarizers can be fitted to any limelight, biunial, or pair of lanterns.

CHAPTER XII

THE PRINCIPLES OF THE OPTICAL LANTERN

THE primitive lantern consists of a luminant, a condenser, an objective, and a reflector, fitted in a box to carry them, and the principle cannot be altered. The luminant has been wonderfully increased in its intensity, the condensers made double or triple, the objective achromatic and spherical and chromatic aberration reduced to a minimum, and consequently larger and brighter pictures are produced, the size of which is only limited by the power of the light produced. When the picture is largest on the screen, then also are all errors at their worst. Fig. 77 will show the section of a lantern of modern construction; H is a square metal box, with an opening at the top and a door at the side; I is an electric light, G is a reflector, O O′ are plano-convex lenses, *a* and *b* two achromatic pairs of lenses, S a milled head, by means of which the achromatic system may be made to approach or recede from the transparent slide, which is placed in the opening K. The rays of light from the carbons reinforced by the reflection from G, and falling upon the lenses O O′, are made almost parallel. These two lenses are consequently called the condensers. The rays next pass through the more or less transparent object placed at K, and by means of the lenses *a*, *b*, an image is formed on a screen placed at a suitable distance to receive it. The image is, of course, inverted, and to be seen erect the object must be necessarily placed in the carrier in an inverted position.

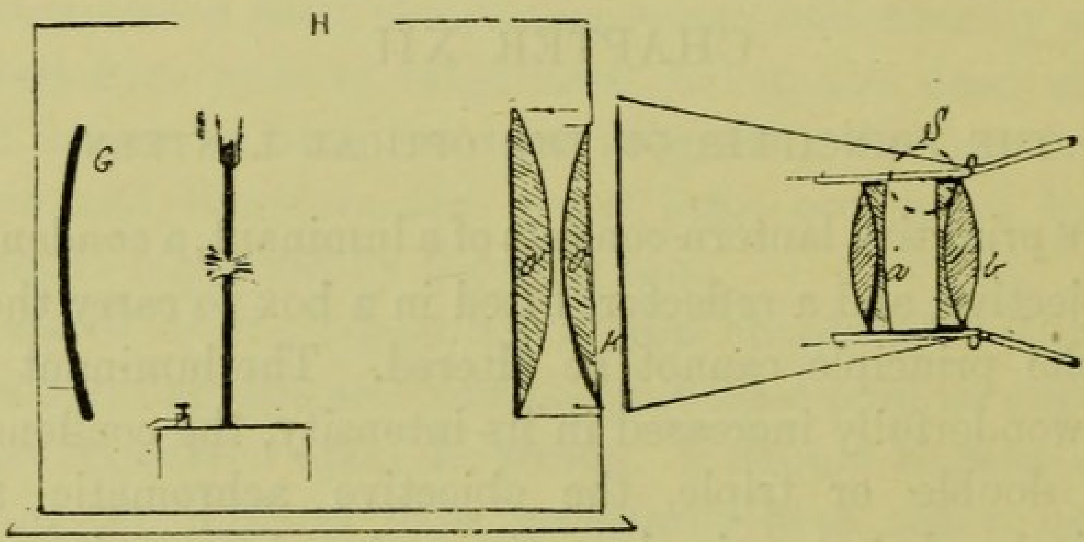


FIG. 77.

ERECTING PRISMS.—The erection of the object can be easily done by introducing an equilateral rectangular prism in front of the lens tube, so that the hypothenuse surface is horizontal. The parallel rays, falling on the prism, are inverted in consequence of refraction at the sides, and reflection from the hypothenuse surface, so that an erect image is obtained instead of the inverted one. The dotted lines, Fig. 78, *a b c d* and *e f g h* will show the path of the two rays. The magnifying power of a lantern is obtained by dividing the distance of the lens from the image by its distance from the object. If the image is 100 or 1000 times farther from the lens than the object, the image will be 100 or 1000 times as large. Hence an objective of short focus will produce a very large image,

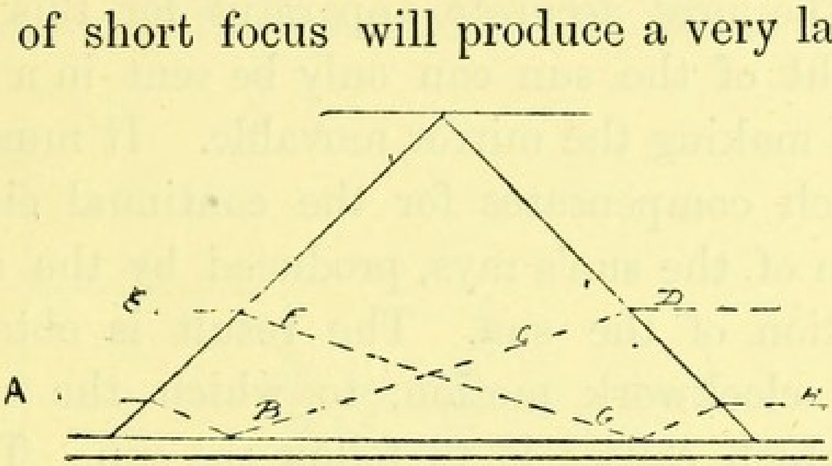


FIG. 78.

provided the screen be large enough, and the illuminant sufficiently powerful.

THE SOLAR LANTERN.—Using the sun as a source of light, we get the solar lantern; this serves to produce highly-magnified images of very small objects. The apparatus, of which Fig. 79 is a section, is fixed in a

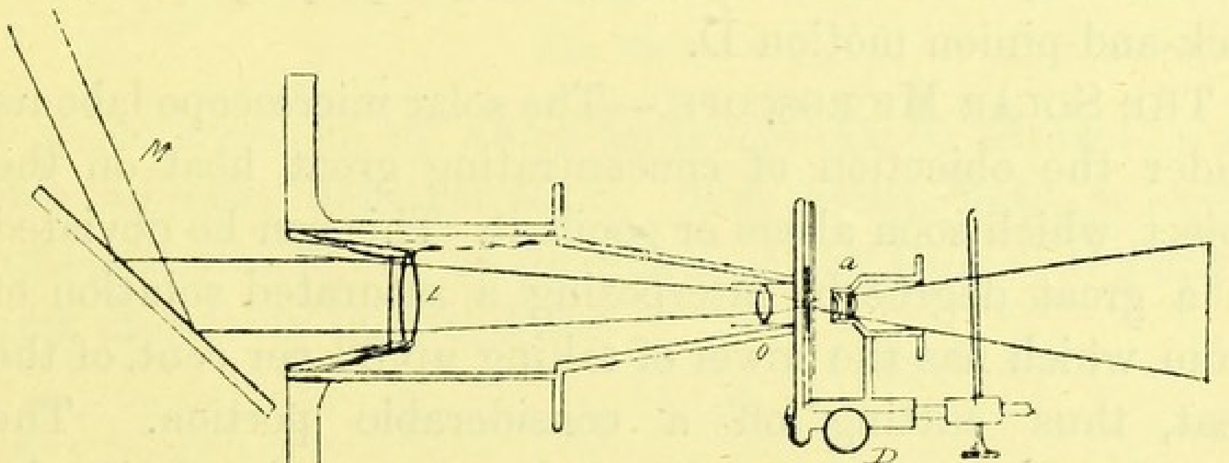


FIG. 79.

shutter of a room, and as the direction of the sun's light is continually varying, the position of the reflector outside the shutter must be changed, so that the reflection is always in the direction of the axis of the microscope. A heliostat is the most accurate apparatus for this purpose, and the light of the sun can only be sent in a constant direction by making the mirror movable. It must have a motion which compensates for the continual change in the direction of the sun's rays, produced by the apparent diurnal motion of the sun. The result is obtained by means of a clockwork motion, to which the mirror is fixed, and which causes it to follow the sun. The sun's rays falling on the mirror M, are reflected towards a condensing lens, L, and thence to a second lens, O, by which they are concentrated at its focus. The object is placed at this point, which is identical to the stage of an ordinary microscope, and clamped by means of spring clips. The object being thus strongly illuminated, the image is formed by a system of lenses, *a*, and projected on to a screen, the lenses focussed accurately by means of the rack-and-pinion motion D.

THE SOLAR MICROSCOPE.—The solar microscope labours under the objection of concentrating great heat on the object, which soon alters or spoils it. This can be obviated to a great degree by interposing a saturated solution of alum, which has the power of taking up 88 per cent. of the heat, thus cutting off a considerable portion. The magnifying power may be deduced experimentally by substituting for the object a micrometer. The division being known as to their distance apart, the magnifying power may be calculated. An electric microscope can be formed by taking the front combination from Fig. 77, and substituting an apparatus like Fig. 79, of course without the reflector. The image from this can either be received on a screen, or by the introduction of a prism at H. Fig.

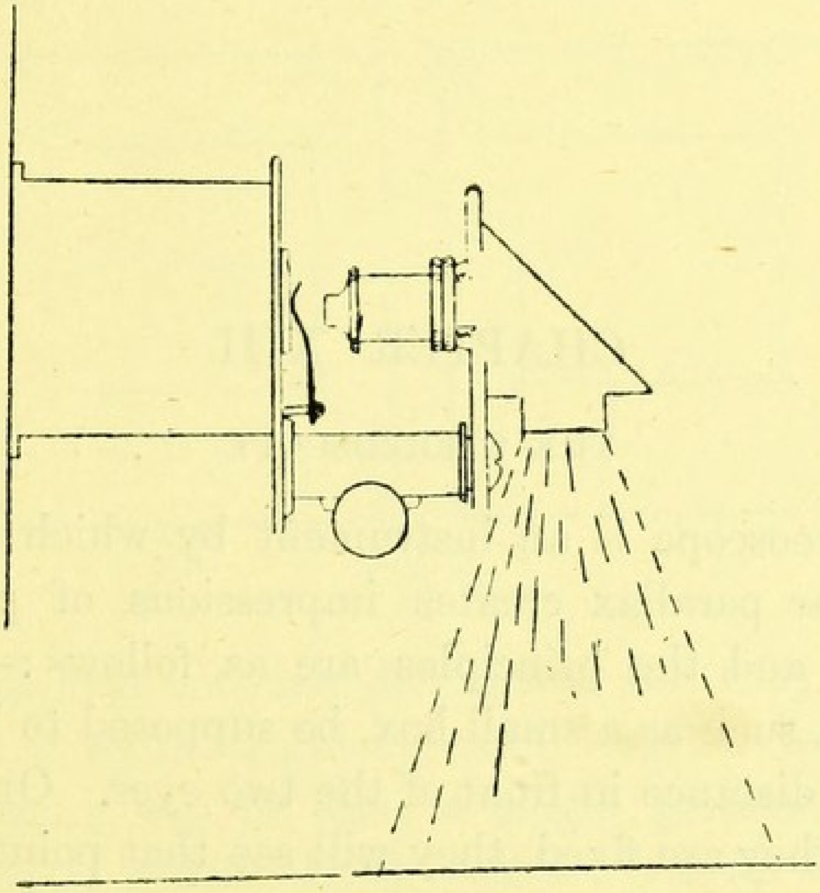


FIG. 80.

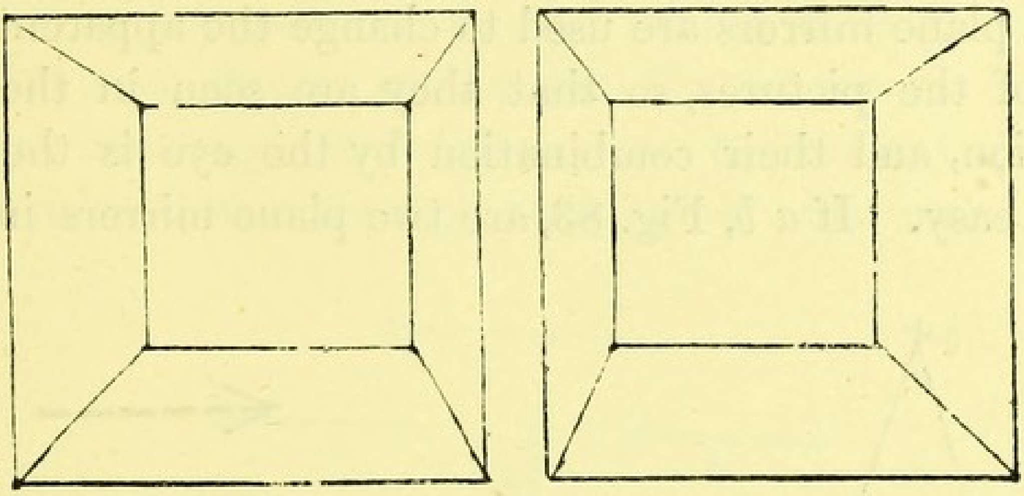
80 shows a system by which an image can be thrown on a table for class demonstration. The electric light, or oxy-hydrogen, which can be produced at any time of the day, is far preferable to solar light.

CHAPTER XIII

THE STEREOSCOPE

THE stereoscope is an instrument by which the effect of binocular parallax creates impressions of perspective and relief, and the principles are as follows:—Let any solid object, such as a small box, be supposed to be held at some short distance in front of the two eyes. On whatever point of it they are fixed, they will see that point the most distinctly, and other points more or less clearly. But it is evident that, as the two eyes see from different points of view, there will be formed in the right eye a picture of the object different from that formed in the left; and it is by the apparent union of these two dissimilar pictures that we see the object in relief.

If we delineate the object first as seen by the right eye and then by the left, and afterwards present these dissimilar pictures again to the eyes, taking care to present to each eye that picture which was drawn from its point of view, there would seem to be no reason why we should not see a representation of the object as we saw the object itself in relief. If the object held before the eyes were a truncated pyramid, *r* and *l* would represent its principal lines (Fig. 81) as seen by the right and left eye respectively.



L FIG. 81. R

If a card is held between the figures, and they are steadily looked at, *r* by the right eye and *l* by the left, for a few seconds, there will be seen a single picture having the appearance of relief. Even without a card between, the eye, by a little practice, can be taught to combine the two and form a solid picture. Three pictures will in this case be seen, the centre one solid and the outside one flat. Let *r* and *l*, Fig. 82, be any two corresponding points—say the points marked by an *x* in the figures; R and L the positions of the right and left eyes. Then the right eye sees the point *r* in the direction R *o*, and the left eye the point *l* in the direction L *o*, and accordingly each by itself judging only by the direction; they together see both points as one, and imagine it to be situated at *o*. But the right eye, though looking in the direction R *r*, also receives an image of *l* on another part of the retina, and the left eye an image of *r*, and thus three images are seen. A card placed between, where the dotted line is seen in Fig. 82 will cut off the two side pictures.

THE REFLECTING STEREOSCOPE.—In the reflecting stereoscope, plane mirrors are used to change the apparent position of the pictures, so that they are seen in the same direction, and their combination by the eye is thus rendered easy. If *a b*, Fig. 83, are two plane mirrors inclined

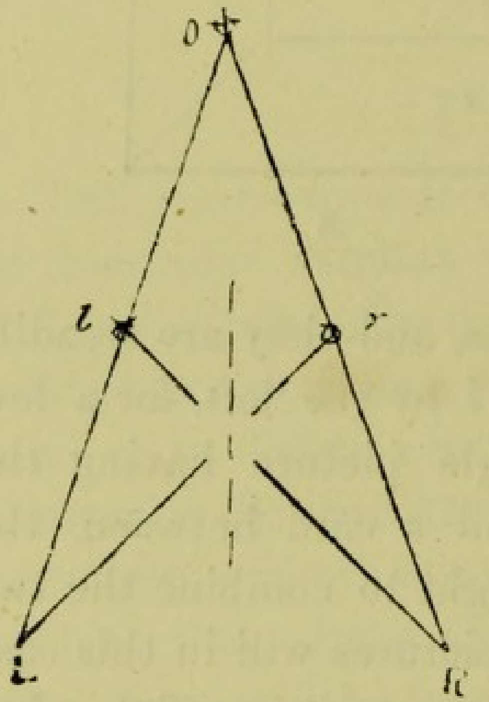


FIG. 82.

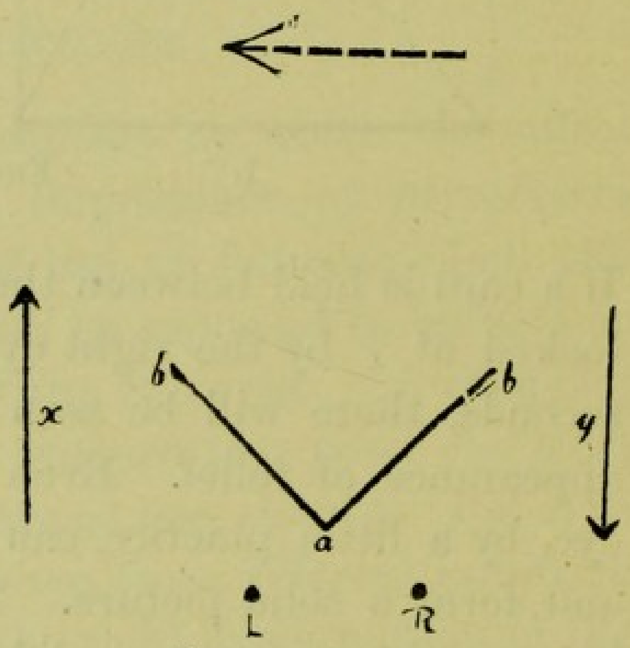


FIG. 83.

to one another at an angle of 90°, the two arrows *x y* would both be seen by the eyes situated at R and L in the position marked by the dotted arrow. If, instead of the arrows, we now substitute such a pair of dissimilar pictures as we have spoken of above of the same solid object, it is evident that if the margins of the pictures coincide, other points of the picture will not. The eyes, however, without effort will bring such points into coincidence, and in so doing make them appear to recede or advance as they are farther apart or nearer together than any two corresponding points of the margins when the pictures are placed side by side, as in Fig. 83. It will be plain, also, on considering the position for the arrows in Fig. 83, that to adopt such figures as those in Fig. 82 for use in a reflecting stereoscope, one of them must be reversed or drawn, as it would be seen through the paper if held to the light.

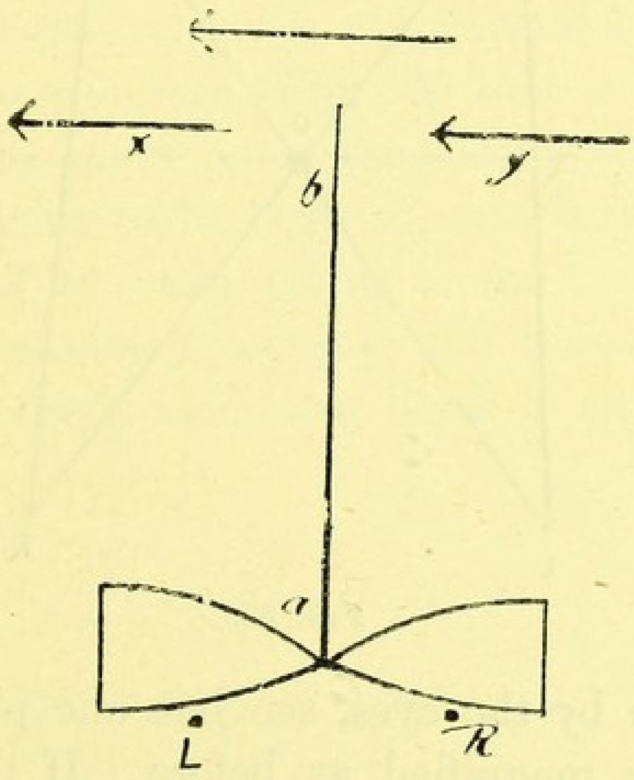


FIG. 84.

THE REFRACTING STEREOSCOPE.—In the refracting stereoscope the rays of light passing through a convex lens are always bent towards the thicker part of the lens. Any segment of such a lens may be adapted to change the apparent position of any object viewed through it.

If (Fig. 84) two segments be cut from a double convex lens and placed with their edges together, the arrows x y would both be seen in the position shown by the dotted arrow, the eyes being at R and L. If we substitute for the arrows two dissimilar pictures of the same solid object, or the same picture, we shall then, if an opaque screen, *a b*, be placed between the lenses to prevent the pictures being

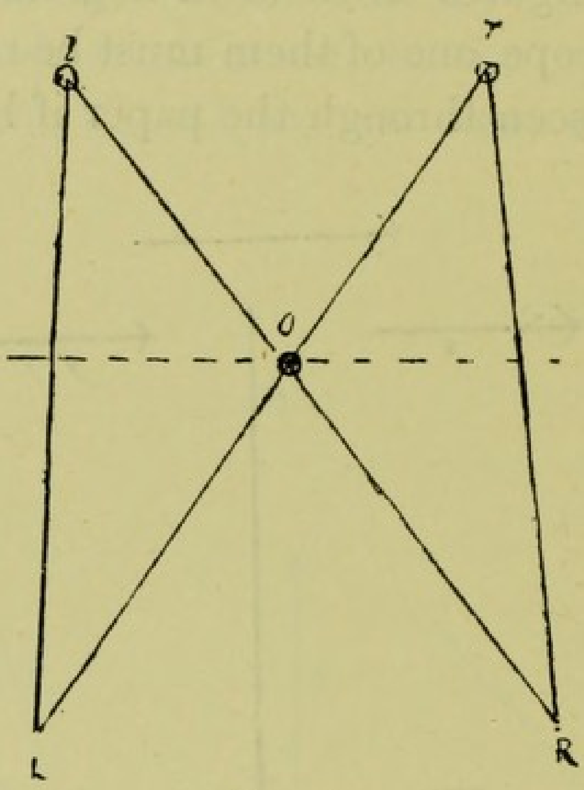


FIG. 85.

seen crosswise by the eyes, see but one picture, and that in the centre magnified as before. If the margins are brought by the power of the lenses to coincide, other corresponding points will not be coincident until combined by an effort of the eyes, which, however, is very slight. Any pair of corresponding points which are farther apart than any other pair will be seen farther back on the picture.

It will be noticed that there is also a second point on this side of the paper, at which, if a person looks steadily, the diagrams in Fig. 85 will combine and form a different stereoscope picture; instead of a solid, a hollow, pyramidal box will be seen, and the two external images will also be seen. If we wish to shut these out and see only the central stereoscopic effect, we must use a screen held parallel to the plane of the picture with a square hole in it. This screen must be so adjusted that it may conceal the right-hand figure from the left eye, and the left-hand figure from the right eye, while the central stereoscopic picture will be seen through the central hole. It will be plain from the diagram (Fig. 85) that *o* is the point to which the eyes must be directed, and at which they will imagine the point to be situated, which is formed by the combination of the two points *r* and *l*. An achromatic combination, balsamed together and then slit through the centre, can be easily made and fitted to any suitable case.

CHAPTER XIV

THE SPECTROSCOPE

THE spectroscope, which is an instrument employed in the study of the spectrum (Fig. 86), is composed of three

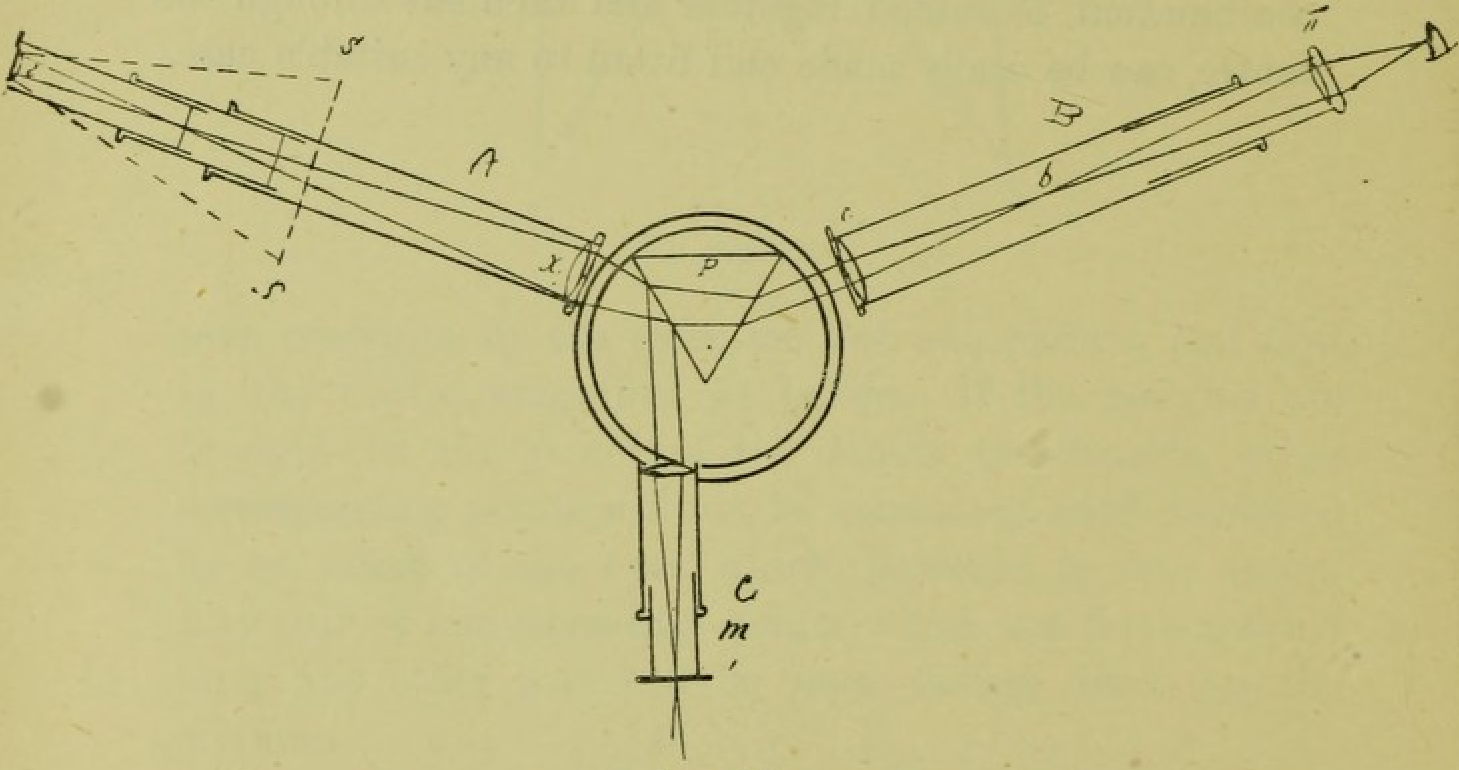


FIG. 86.

telescopes mounted on one foot, the axis of each converging a prism of flint glass, the telescope A having a circular motion, the other two being rigid. The rays emitted by the flame G fall on the lens *a*, and are caused to converge to a point, *b*, which is the principal focus of a second lens, *c*. Thus the pencil of light on leaving the telescope B is made parallel, and enters the prism P. On leaving the prism the light is decomposed and falls on the lens *x*. By this lens *x* a real and reversed image of the spectrum is formed at *i*. This image is seen through a lens which forms at S S a virtual image of the spectrum magnified. The telescope C serves to measure the distances of the lines of the spectrum, and is provided with a micrometer placed at *m*. In the direct-vision spectroscope prisms are combined so as to get rid of the dispersion without entirely destroying the refraction (Fig. 87). They may conversely be combined, so that the light is not refracted, but decomposed, and produces a spectrum. A system of two flint and three crown-glass prisms is placed in a tube, which slides in a second one. At the end of this is an aperture, *o*, and inside it a slit, the width of which can be regulated by turning the ring

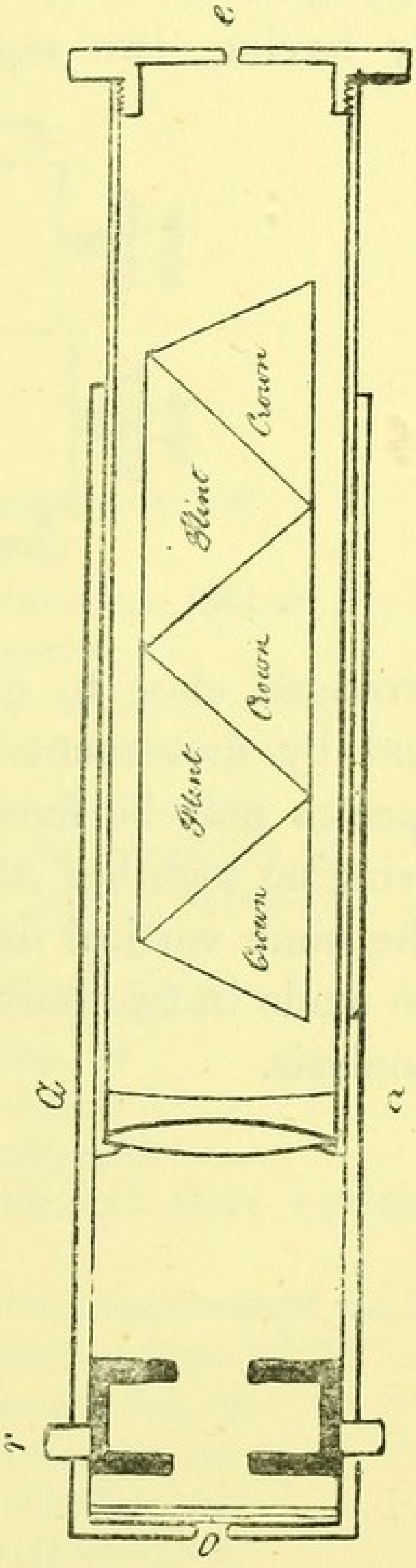


Fig. 87.

r. A small achromatic lens is placed at *a a*, the focus of which is at the slits, so that the rays pass parallel through the five prisms, and the spectrum is viewed at *e*. By having two equal systems of direct-vision prisms

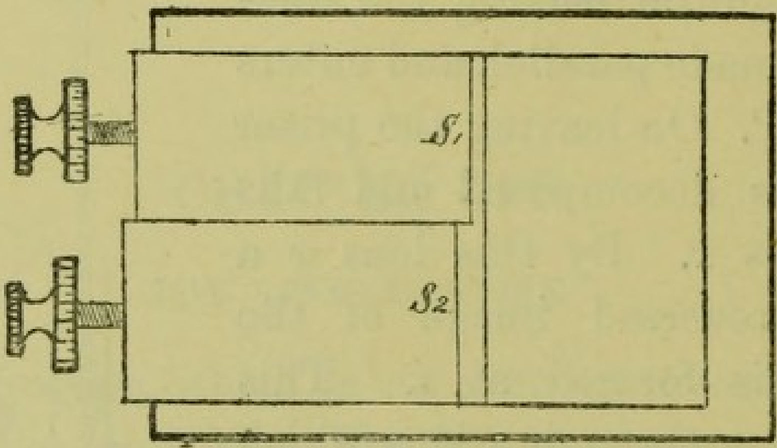


FIG. 88.

arranged close to each other, the spectrum is reversed, and by movement of a split lens the position of the spectra may be moved apart or nearer to each other, and bringing together any two lines so that they may be in the same vertical line. The slit of the spectroscope can be made in two halves (Fig. 88) for quantitative spectrum analysis.

THE END.

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