James Lackington

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Birmingham

THE KEY TO
Sight Testing.

By

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AND

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SECOND EDITION.
REVISED AND ENLARGED.

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Preface

to the Second Edition.

THE demand of Opticians for increased knowledge has necessitated considerable enlargement of "The Key to Sight Testing," and in the endeavour to supply this in so many different departments of Optics I have thought it better again to invite co-operation.

The Chapters written in conjunction with my friend the late Mr. William S. Baxter have been revised, and, in many instances, enlarged, while I am indebted for much of the new matter to Mr. Val H. Mackinney, whose experience as a teacher of Optics has proved very valuable.

In addition I have to thank many readers of the original edition for various suggestions.

January, 1908.

H. L. T.

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Section I.

Geometrical and Physical Optics.

Chapter I.

CURVATURE SYSTEM AND OPTICAL NOTATION.

WHEN a stone is thrown into water we notice that concentric circles of ripples emanate from the point of disturbance, and that any straight line from that point to any circle measures the distance of the ripple from the point of origin. Without pressing the analogy too closely we may illustrate the progress of light waves from a luminous point by this illustration, and as light travels in straight lines a *ray* corresponds to any straight line from the centre, so that it becomes a *radius* for any given ripple or wave, and is thus the *path of a wave*.

The curvature method of treating geometrical optics so simplifies the teaching of this branch of the science, that one wonders why so many writers have given it such slight recognition. This method deals with the subject strictly from the physical standpoint, and in accordance with the generally accepted wave theory of light. It lends itself to the satisfactory explanation of the phenomena of physical optics, and thus in many instances cumbersome mathematical proofs may be replaced by simple reasoning—in conjunction with a graphical representation. Furthermore, it offers an especial advantage because it harmonizes with the spectacle-lens notation now used by opticians. The introduction of the curvature method into the present volume will enable the reader to grasp the subject much more readily and to retain the knowledge so gained.

It is evident that we need some unit by means of which we can get a definite idea of the value of certain measurements, the simplest of which is that of length. We may express this in the standards known as feet, inches, metres, etc., but in addition we must know the point of origin and the direction of measurement. Optical measurements of distance are now universally made according to tbe metric system, and specified as so many metres (m), centimetres (cm), or millimetres (mm).

The unit of curvature is defined as that curve which corresponds to a radius of one metre (39·37 or approximately 40 inches) and is called a *dioptre*.* It may be used to express the curvature of a beam of light, mirror, or lens surface, as well as the power of a lens, as will be seen presently.

Similarly, the unit of angular measurement is defined as that angle which, at the centre of a circle, stands on an arc equal in length to the radius of the circle, and is called a *radian*.

Let any circle ABC be taken, Fig. 1 (we may with advantage think of this as a sphere), this circle has a definite fixed radius r. The curvature may be represented by R and defined as follows :—

The curvature of a circle is the angle through which a curve turns per unit length.

If, therefore, we denote the angle by θ, and its corresponding length of arc by l, we have by definition—

$$R = \frac{\theta}{l} \tag{1}$$

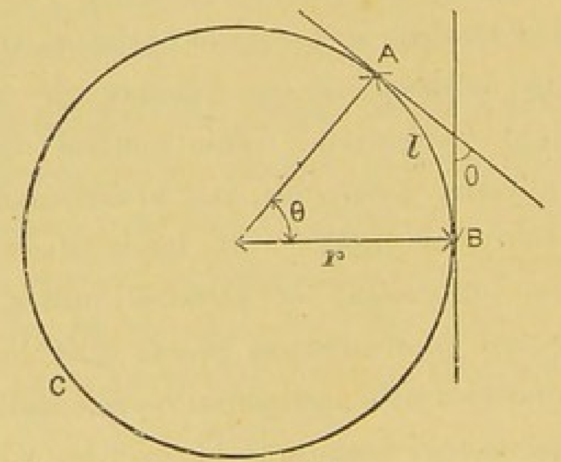


Fig. 1.

Also, from the definition given above of the unit of angular measure—the radian—it is seen that :

$$\theta \text{ (in radians)} = \frac{\text{arc}}{\text{radius}} = \frac{l}{r}$$

$$i.e.: \quad l = \theta r.$$

Substituting this value of l in (*1*)

$$R = \frac{\theta}{\theta r} = \frac{1}{r}$$

---

* The word *dioptrie* was proposed by Monoyer in 1872 and adopted by the Brussels International Congress in 1875.

Expressing this in words we have : *The curvature of a circle (or surface) is the reciprocal of its radius.*

From the definition of unit curvature, when r = 1 metre, 100cm, or 1000mm.
= 40 inches (approx.)
then R = 1 Dioptre.

It is therefore seen that R, the curvature of the light wave, or any other surface, real or imaginary, is given in dioptres when the radius of curvature is known, no matter in what units the radius may be given.

$$R \text{ (The curvature of the surface in dioptres)} = \frac{1}{r \text{ (in metres)}}$$

$$= \frac{40}{r \text{ (in inches)}} \quad \text{since 40 inches} = 1 \text{ metre (approx.)}$$

$$= \frac{100}{r \text{ (in centimetres)}} \text{ or } \frac{1000}{r \text{ (in millimetres)}}$$

The following table shows that as R increases so r decreases.

Radii of Curvature (r) in metres and inches		Curvatures (R) in Dioptres
1 metre	40 inches	1 D
2 „	80 „	$\frac{1}{2}$ D
4 „	160 „	$\frac{1}{4}$ D
$\frac{1}{2}$ „	20 „	2 D
$\frac{1}{5}$ „	8 „	5 D
$\frac{1}{10}$ „ (10cm)	4 „	10 D

The dioptre as a unit is one very useful to opticians in general ; when, however, we have to deal with microscope and other lenses, whose surfaces often have curves with radii of the order of a few millimetres, or telescope lenses for the great "refractors," the radii of whose surfaces may measure several metres, then it becomes advisable to adopt multiples and sub-multiples of this unit. Dr. Drysdale* has suggested the following :—

RADIUS OF CURVATURE.	CURVATURE.
Kilometre.	Millidioptre.
Metre	Dioptre.
Centimetre.	Hectodioptre.
Millimetre.	Kilodioptre.

These are admirable, for the range of curvatures may be very great.

*Proc. Optical Society, December, 1902.

Light which impinges upon any surface is known as *incident*, while that which is returned from the surface is *reflected* ; and when any is transmitted, after being bent from its course at the surface, it is termed *refracted light*.

As light travels in straight lines there will always be one particular path of a wave perpendicular to the mirror or lens surface. Such a path (*ray*) is said to have *normal* incidence, and all angles of incidence are reckoned from this, and not from the surface itself.

For convenience, a notation* has been adopted in this work, which is now very generally used, by which distances of the point of origin of paths of light, and also points of assemblance of paths, after encountering simple reflecting or refracting surfaces, are denoted by small letters, while capitals are used for the corresponding curvatures of the waves of light at those distances.

In some cases the assemblance of paths is not real, and then by prolonging them backwards a *virtual* point is obtained.

Thus, while u and v symbolize the two distances referred to, U and V represent corresponding curvatures. Similarly, r is used for the radius of curvature of a mirror, and r_1, r_3 (odd numbers) for the radii of curvatures of the surfaces of a lens.

Refractive Indices (see later) are denoted by *even* numbers, for instance n_0, n_2, n_4, etc.

It may further be mentioned that in the use of + and − signs the *product* (multiplication) of like signs is always positive, while that of unlike signs is always negative. So that − (−U) equals +U, etc.

This notation may be brought to a close by asking the reader *always* to consider light as passing from left to right, also to treat divergent light and surfaces curved in the direction of divergent light as *negative*, (Fig. 2) ;

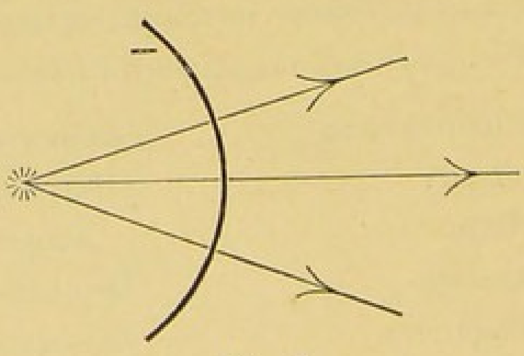


Fig. 2.

* This notation, with slight variations, has been advocated by Herschel, Prof. S. P. Thompson, Dr. C. V. Drysdale and other writers.

but convergent light, and surfaces curved in the direction of convergent light, as *positive*, (Fig. 3).

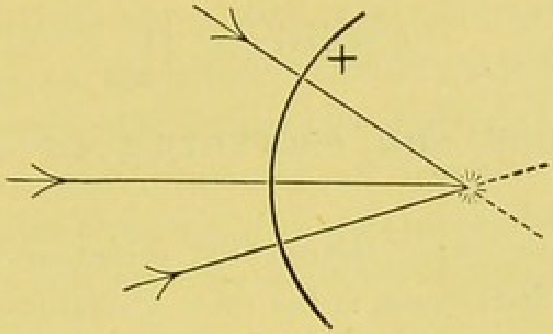


Fig. 3.

By adhering to the above rules, the solution of all ordinary mirror and lens problems becomes an easy matter.

Summary.

(*a*) The radian is the unit of angular measurement.

(*b*) The curvature of a circle is the reciprocal of its radius.

(*c*) Capital letters indicate curvatures, and small letters the corresponding distances.

(*d*) Odd numbers are used for radii, even numbers for refractive indices.

(*e*) Light is considered as passing from L to R.

(*f*) Convergent light and similarly curved surfaces are +, and divergent light and similarly curved surfaces —.

CHAPTER II.

NATURE AND PROPERTIES OF LIGHT.

ACCORDING to the wave theory, the sensation of light is a direct consequence of a disturbance in the *ether*, a substance which it is necessary to conceive, although no eye has seen nor instrument weighed it. Ether is the key to the satisfactory explanation of *all* physical phenomena. As Lewis Wright says in his book on "Light":—

> "Heat, Light, Colour, Electricity, Chemical Actinism,—all alike are "simple disturbances in, or propagations of disturbances through, that "Something which we call Ether. Invisible themselves, these "wonderful motions make all things visible to us, and reveal to us "such things as are."

Light, then, as we understand it, is a transverse (since the vibration is at right-angles to the direction of propagation) undulatory disturbance in this unknown substance. These waves or undulations, once set up, travel at the enormous rate of about 300 million metres per second, and when vibrating at the rate of between 375 and 857 billion times per second, they cause the sensation of light. The rate of vibration also determines our colour sensation. Supposing the range of frequency to be small, and something of the order of 400 billion times per second, then the sensation produced is that of red light: if the frequency is of the order of 500 billion times per second the sensation is that of yellow light: and, finally, if of the order of 700-800 billion times per second the sensation is that of blue or violet light. Should the range of frequency be at all great then the resultant colour sensation will be a compound one, and if it embraces the entire visual range (between 375 and 857 billion times per second) then the resultant sensation will be that of white light.

In Fig. 4, let us suppose that light has travelled from the point A to the point B in one second. Then the distance AB represents 300 million metres, or 300,000 million millimetres. The light vibrates in a transverse direction, that is, at right-angles to the line of propagation AB.

CD represents one such complete vibration and is *one wave-length.* If the light proceeding from A consists of all vibrations between 375 and 857 billions per second, then the wave-lengths of the wave motions proceeding from A to B will differ one from another. We have reason for believing that the velocity for any coloured light is practically the same in air and free space; in other media, however, the bending of the path of the light due to refraction is a consequence of a change in velocity, and experiments show that the change in velocity is dependent upon the colour of the light—in other words, upon the frequency of vibration, or wave-length, of the incident light.

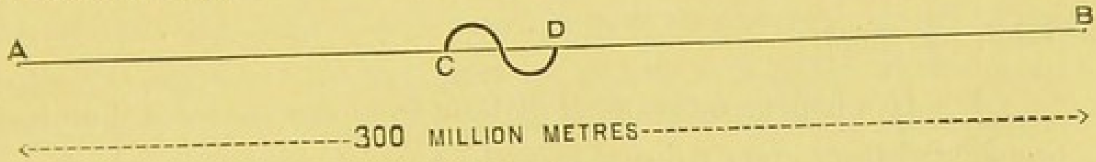


Fig. 4.

It is not a difficult matter to realize therefore, that under certain circumstances a composite beam of light may be split up into its component parts, and such breaking up is termed *dispersion.* Light of one particular rate of vibration, and therefore of one particular wave-length, is called *monochromatic light.* Sunlight may be split up into a number of coloured lights, viz.:—red, orange, yellow, green, blue, indigo, and violet. One way of breaking up the light is by passing it through an optical prism (Chapter VI.), the resultant band of different coloured lights being termed a *spectrum*, and in the case of sunlight—the solar spectrum.

The connection between velocity, frequency of vibration, and wave-length of light may be represented by $f = \frac{V}{\lambda}$; where f denotes the frequency of vibration per second, V the distance traversed per second, and λ the wave-length.

From which we see that $\lambda = \frac{V}{f}$

Now the frequency (375 billions per second) which produces the sensation of red light represents one limit of the visual spectrum, so that frequencies below this do not produce the sensation of light at all in the human eye. Also the frequency (857 billions per second) which produces the sensation of violet light represents the other limit of the visual spectrum.

As the velocity in air or free space is the same for all colours, viz.: 300,000 million millimetres per second, we have

For Red Light the limiting wave-length

$$\lambda_r = \frac{300{,}000 \text{ million}}{375 \text{ billion}} \text{ mm.} = \cdot00080 \text{ mm.}$$

For Violet Light the limiting wave-length

$$\lambda_v = \frac{300{,}000 \text{ million}}{857 \text{ billion}} \text{ mm.} = \cdot00035 \text{ mm.}$$

The Greek letter μ (pronounced "mu") is employed by many to denote 1 micron, that is, $\frac{1}{1000}$th mm. (·001 mm.), while others employ the same symbol to denote "refractive index." In this work it has the former signification. We may say, therefore, that the visual spectrum ranges from 0·35 μ (violet limiting wave-length) to 0·80 μ (red limiting wave-length).

The Laws of Light.

1. In a homogeneous medium light from any source of illumination is propagated from every point of it in the form of concentric spherical waves which spread outwards in the direction of the radii of their spheres.

From this law follows the *rectilinear propagation of light*, in other words light travels away from its source in every direction in straight lines.

2. The intensity of illumination at a given point varies inversely as the square of its distance from the source of illumination. This is known as *the law of inverse squares.*

3. The intensity of illumination which is received obliquely is proportional to the cosine* of the angle of turning of the surface.

The intensity of illumination of any surface is the amount of light received on unit area of that surface. The unit of illumination is that given by a light of unit brightness at unit distance. In England the practical unit may be taken as that illumination given by a standard candle at a distance of one metre, and called one *candle-metre.*

The intensity of a source of light is the amount of light emitted as compared with that from a standard source of illumination. The British standard is a particular candle burning 120 grains of pure spermaceti wax per hour. The practical standard, however, is the Vernon-Harcourt 10 c.p. Pentane Lamp, having a light intensity extremely constant with careful use, which cannot be said of the standard candle.

If I denotes the illumination, K the candle-power, and *d* the distance

*For explanation see Tables at end.

of the receiving screen from the source; then, from the law of inverse squares we have

(1) $I = \frac{K}{d^2}$ when the receiving screen faces the source normally.

(2) $I = \frac{K}{d^2} \cos a$ where a is the angle of turning of the surface from its position when it faced the source normally.

The quantity of light Q received by any surface is given by Lambert's equation

(3) $Q = B \frac{A_1 A_2}{d^2} \cos a_1, \cos a_2,$ where A_1 and A_2 are the areas of the luminous source and screen respectively, d the distance between the centres of the two surfaces, and a_1 and a_2 the angles made by the imaginary line joining the two surface centres with their respective normals. (Fig. 5.)

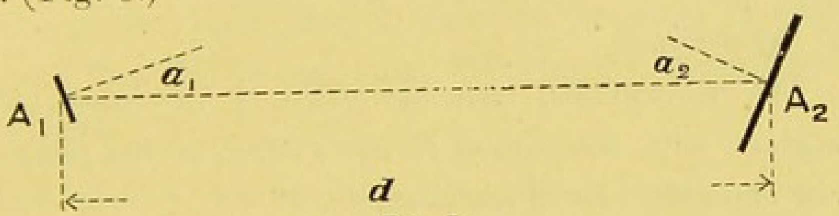


Fig. 5.

All these equations (1) (2) and (3) are only correct when the dimensions of the luminous source are small as compared with the distance d.

In practice equation (1) is of great use, for by means of it we are able, with a photometer, to compare the intrinsic brilliancy of two light sources, by reducing to equal illumination the light given out by them.

The essentials of the photometric process are first, the production of two identical surfaces (or one surface), illuminated separately from each source; and secondly, some means of obtaining equality of illumination on the said identical surfaces (or one surface).

The Aberration of Light. Owing to the facts that light travels with a finite velocity, and that the earth has a certain period of revolution round the sun, light emitted by the heavenly bodies will, more often than not, appear to have proceeded along a different path from what it really has, and we see them in a false position; hence the term "aberration of light."

The Laws of Reflection.

1. The incident and reflected paths of the waves of light lie in the same plane with the normal to the surface at the point of incidence, and are on opposite sides of the normal.

2. The angles which the incident and reflected paths of the waves of light make with the normal to the surface are equal to one another.

From these two laws we see that in Fig. 6, first, the incident path B, reflected

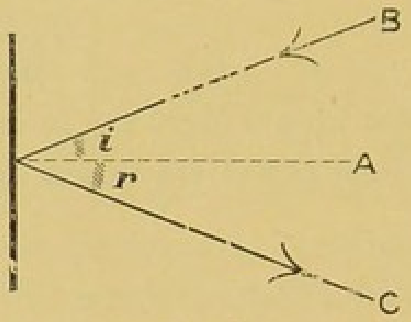


Fig. 6.

path C, and normal A, all lie in the plane of the paper; secondly, the reflected path is on the opposite side of the normal to the incident path: and thirdly, the angles i and r are equal to one another.

The Laws of Refraction.

1. The incident and refracted paths of the waves of light lie in the same plane with the normal to the surface at the point of incidence, and are on opposite sides of the normal.

2. For light of any one colour the sines of the angles of incidence and refraction are in a constant ratio for the two media. (Snell's law).

From these two laws we see that in Fig. 7, first, the incident path B, refracted

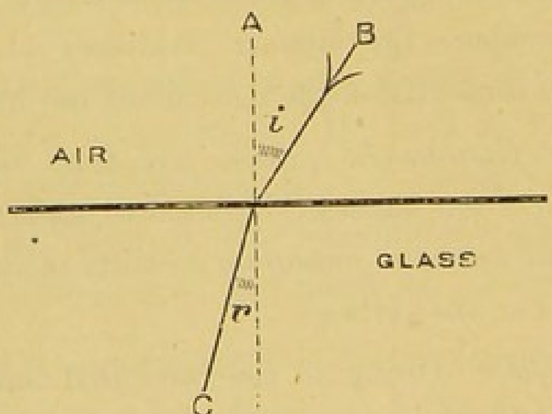


Fig. 7.

path C, and normal A, all lie in the plane of the paper; secondly, the refracted path is on the opposite side of the normal to the incident path; and thirdly, $^{*}\frac{\sin i}{\sin r} = K$, a constant for the same two media and for light of a particular colour.

*For explanation see Tables at end.

Refractive Index.

The *absolute* refractive index of a substance is simply the ratio between the velocity of light in free space, or air for all practical purposes, to its velocity in the substance under consideration. If, therefore, we denote the velocity of light in free space or air by V_0, the velocity in the substance by V_2, and the refractive index by the letter n, then we have

$$n = \frac{V_0}{V_2}$$

V_0 for air we have seen is equal to 300 million metres per second. Now the velocity in a certain kind of crown glass is about 200 million metres per second, therefore the refractive index $n = \frac{V_0}{V_2} = \frac{3}{2} = 1.5$.

In transparent media other than gases, the change of velocity is dependent upon the colour of the light, that is, upon the frequency of vibration or wave, length ; so that the above value will only be correct for a particular coloured light.

In practice it is usual to determine the refractive indices for red, yellow and blue light. The yellow chosen is that given out by luminous sodium vapour, readily produced by burning common salt in a Bunsen flame. The spectrum given by this is simply a narrow band of yellow light—in reality double—so that, for all practical purposes it is monochromatic, and when a refractive index for any substance is stated without reference to any colour it may be assumed that it refers to this yellow sodium light.

Since the band is quite narrow we may assume that it has but one frequency, and therefore one particular wave-length, given as $\lambda = 0{\cdot}5890\ \mu$.

The spectrum of luminous hydrogen vapour consists of four very narrow bands or lines of light. These are red, green, blue and violet in colour, and the refractive index of a piece of glass is usually determined for the red and blue lines of hydrogen, as well as for the yellow line of sodium, the reason for which will be apparent when we have studied Chapter VI.

It is usual to denote the refractive index for sodium light by the symbol n_D, and the refractive indices for the red and blue lines of hydrogen by n_C and n_F respectively. n_D represents the *mean refractive index*. The difference between n_F and n_C $(n_F - n_C)$ is a measure of the dispersion of the glass, and may be termed the *mean dispersion*.

The *dispersive power* ω is given by the equation $\omega = \frac{n_F - n_C}{n_D - 1}$, where 1 is the refractive index for air. (The actual figures being 1.0002922.)

The *dispersive reciprocal* or *efficiency* N is therefore given by

$$N = \frac{n_D - 1}{n_F - n_C}.$$

All the above constants are given in their lists by makers of glass so as to enable purchasers to get some idea of the properties peculiar to the various glasses. Partial dispersions in three portions of the visual spectrum are given too.

The refractive index n, which by definition is equal to $\frac{V_0}{V_2}$ is also equal to $\frac{\sin i}{\sin r}$, where i is the angle of incidence, and r the angle of refraction.

We may see that $n^* = \frac{V_0}{V_2} = \frac{\sin i}{\sin r} = \frac{n_2}{n_0}$, where n_2 is the refractive index for the second medium and n_0 the refractive index for the first medium.

Let BD in Fig. 8 represent the surface of separation between two media whose refractive indices are n_0 and n_2 respectively, n_2 being the greater. Let CD represent the path of the incident plane wave front BC, the normals to the surface being shown as dotted lines. Had the light not met the new medium n_2, in a given time the point B would have travelled a distance equal to CD, but because it meets the new medium the wave front is retarded and bent out of its course, and the point B will only reach E in a given time.

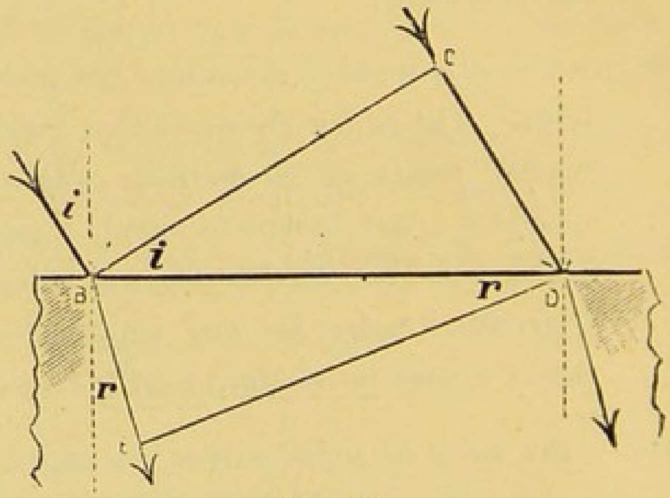


Fig. 8.

BCD and BED are right angled triangles because the path of a plane wave is at right angles to the wave front. Therefore the angle which the path makes with the normal, and the angle which the wave front makes with the surface are both angles of incidence (i). Similarly those marked (r) are the angles of refraction.

* When V_0 represents the velocity in any medium but air, n is termed the *relative* refractive index; n_0 for air = 1, therefore $n = n_2$ usually.

Now $\sin i = \frac{CD}{BD}$ and $\sin r = \frac{BE}{BD}$

And $\frac{\sin i}{\sin r} = \frac{\frac{CD}{BD}}{\frac{BE}{BD}} = \frac{CD}{BE}$

But CD and BE represent the velocities V_0 and V_2

$$\therefore n = \frac{V_0}{V_2} = \frac{\sin i}{\sin r} = \frac{n_2}{n_0}$$

The above holds good for all angles of incidence. We know also, from our second law of refraction, that for two given media, and a particular colour of light, $\frac{\sin i}{\sin r}$ is a constant.

Diffraction. Although we may consider light as a grand wave motion and represent it diagramatically by concentric circles, experiment shows that the motion set up in the ether is a very complex one indeed.

In Fig. 9 let O be a luminous source, then if A B is the first main or *grand* wave, it will be formed by the mutual interference of the little *secondary* waves, which all assist to that end. If C D is an aperture, then only a portion of the main wave can pass on, and at each edge of the aperture some of the secondary waves will become detached from the main beam and proceed in the direction shown, very diagramatically, by the arrows. Some of these will meet in opposition and destroy one another, others will meet in such a manner as to assist one another, the final result being that to an eye placed on either side of the transmitted portion of the main wave, alternate dark and light bands of light will appear. If the source O is white, or other compound light, then alternate dark and spectral coloured bands will be seen. This is one method of producing diffraction spectra, and the further we move the eye from the main beam the fainter will become the luminous diffaction bands or spectra.

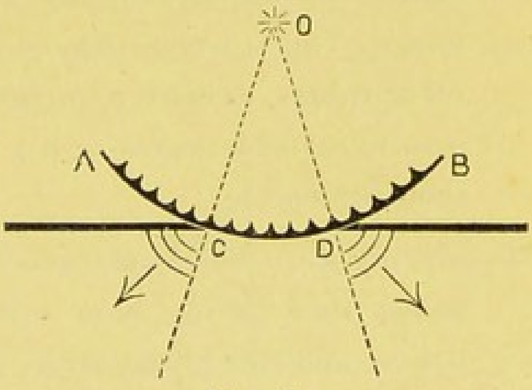


Fig. 9

Interference. Just as secondary waves assist or annul one another, so do main waves assist or annul one another. But here at least two sources, or two apparent sources, of illumination are necessary. Phenomena due to the interference of the main waves of light are called *interference phenomena.*

Polarization. Experiment shows that however light is vibrating when proceeding from its source, oblique reflection and unequal refraction (as seen in doubly refracting crystals) have the property of splitting the light up into two paths, a particular percentage of the light along each of which has a purely transverse vibration ; that is, it vibrates in one plane only. Experiment also proves that the light following each of these paths is vibrating in a direction at right-angles to the other. Often it will be found that the sorting out of the vibrations has not been complete, and that a certain amount of residual ordinary white light is still present. Light vibrating in one plane only is said to be completely plane polarized. Phenomena due to the polarization of light are studied under the title of " Polarization."

Fluorescence. Certain substances, such as a solution of sulphate of quinine, or a piece of Uranium glass, possess the property of converting some of the shorter wave-lengths of light into longer ones, and transmitting them as such. This is termed Fluorescence, and by means of it we are able, among other things, to convert invisible light into visible light, in other words, to give to invisible waves such a wave-length as will enable our eyes to detect their presence.

Phosphorescence. Some substances possess the property of giving out luminous waves after having been withdrawn from the presence of any luminous source, and this phenomenon is called Phosphorescence. It is simply a case of energy being stored at a greater rate than it is emitted. Fluor spar glows for a short period after exposure to a strong light, while certain sulphides, and the compound sold as Balmain's luminous paint, glow for many hours after exposure to a strong light.

Calorescence. Certain substances possess the property of converting the longer wave-lengths into shorter ones ; it is thus the converse of fluorescence.

Summary.

(*a*) The visible spectrum ranges between 0.35 μ and 0.8 μ.

(*b*) Monochromatic light is of one particular wave-length.

(*c*) The intensity of illumination varies inversely as the square of the distance.

(*d*) The angle of incidence of light is equal to the angle of reflection.

(*e*) $\frac{V_0}{V_2} = \frac{\sin i}{\sin r} = \frac{n_2}{n_0}$

CHAPTER III.

REFLECTION AT PLANE AND CURVED SURFACES.

Experiment. Hold some small source of illumination in front of a *thin* piece of plane mirror, and note that the image apparently occupies a similar position behind the mirror to what the source does in front.

Now replace the thin piece of plane mirror by a *thick* piece, and, looking obliquely, notice that there are *several* images, only one of which occupies a symmetrical position with the object with regard to the silvered surface.

The image seen in the thin plane mirror is a virtual or imaginary one, the object being apparently seen in a position it does not occupy, because the mirror surface alters the course of the actual light waves. In Fig. 10 the actual, but invisible, divergent wave of light AB from the luminous source O, occupies a momentous position. At A it is about to be reflected, while at B it has a distance B B_1 to travel before reflection, and it is obvious that by the time B reaches B_1, A will have reached A_1. Had the mirror not been present, A would have occupied the position A_2. In the figure the distances A A_1, A A_2, B B_1 must be equal, on the assumption that light travels away from its source in spherical waves, and that reflection is instantaneous, or equal in retardation effect at all angles of incidence. Hence the curvature of the wave at the particular moment when it occupies the reflected position at A_1 must be equal to that which it would have at A_2 if the mirror were not present, for the curves stand on the same chord, and have equal sags, under the assumptions made. Therefore, to an eye placed as shown, the object will appear to be at O_1. This apparent position of the object is called the image position—and because the curves above referred to are similar in all respects this apparent object

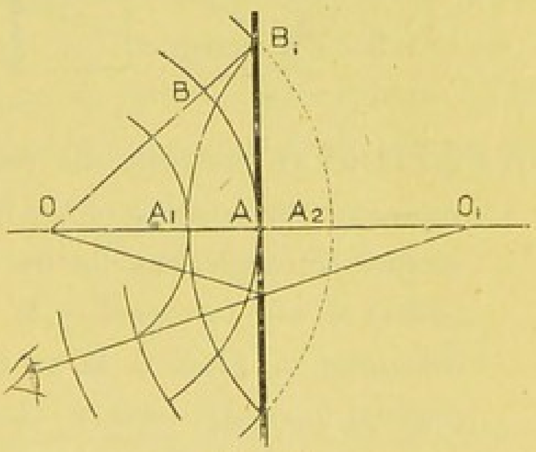


Fig. 10.

O_1 will appear to occupy a similar position to that of the actual object, only on the opposite side of the mirror. If the position of the luminous source be such that the distance represented by $O\ A_2$ or $O\ B_1$ equals one metre, then, since $A_1\ O_1 = O\ A_2$, the reflected wave of light will have a curvature of one Dioptre.

Or replacing the thin mirror by a thick piece, several images of the object will be seen by looking obliquely, a phenomenon of very great importance in optical work. By careful observation we may also note that it is the second image which is the brightest, and that beyond this there seems to be a great number of images, all equidistant, but getting less intense as the apparent distance from the mirror surface increases.

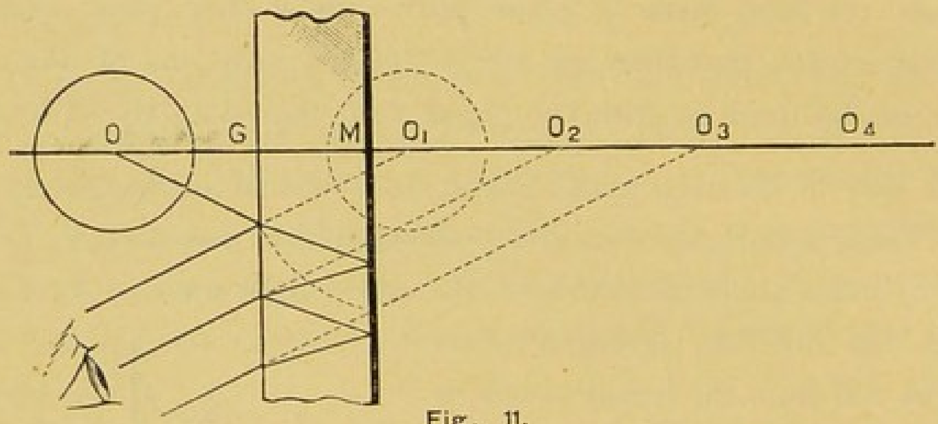


Fig. 11.

In Fig. 11 let O represent the position of the luminous source, then O_2 will represent the position of the image formed by the highly reflecting mirror surface M (neglecting for the moment the effect of refraction at surface G) and O M will be equal to $M\ O_2$. Before the light passes through the thickness of glass G M to the mirror surface M it has lost some of its original intensity, because the surface G, although transparent, possesses the property of reflecting a definite amount. The light reflected by a very perfect transparent glass surface is of sufficient intensity, when the object is a luminous source, to enable an image of the object to be seen by oblique observation. Hence another image O_1, of less intensity than O_2, is seen in front of this bright one O_2, the distance depending upon the thickness of glass G M. The distance O G will be equal to the distance $G\ O_1$.

Just as a certain amount of light is lost by reflection at the glass surface when the light passes from air into glass, so also is another definite amount lost by reflection on the light passing from the glass into air on its return path. This, as the diagram shows, gives rise to a third image O_3. The diagram might be extended to show O_4, O_5 &c., in fact theoretically there is an infinite number of these images, but the formation of each causes a loss in the light which passes on, until finally the intensity of the light is not sufficient to produce another visible image.

When the thickness of glass in front of the reflecting surface does not exceed a few millimetres all the visible secondary images are formed so close to the chief (bright) one O_2 as to become scarcely distinguishable at all moderate angles—say up to 45° from the normal. They may, however, cause the bright image to appear fuzzy, and these multiple images are often the cause of much annoyance in optical instruments, ruining the definition of the bright image. Metallic mirrors, or glass mirrors silvered on the front surface, are sometimes employed, but they become costly if at all perfect in other respects, and are very apt to tarnish or get marked during use.

If a plane mirror is rotated through a given angle, say θ, the light reflected by the mirror will be rotated through just twice the angle, viz., 2θ. This is the principle made use of in instruments like the sextant.

The truth of this will be evident if we consider the movement of the normal to the surface, which rotates exactly to the same extent as the mirror, and as the angle between it and the incident light increases, so will the angle between it and the reflected beam increase, to just the same extent. Thus the reflected beam moves at twice the rate of the normal to the surface, and consequently of the mirror also.

Practical Use of Plane Mirrors.

(*a*) To measure small deflections.

(*b*) In instruments designed for the measurement of angles, as the sextant, range finder, etc.

(*c*) In retinoscopy.

(*d*) In the kaleidoscope.

(*e*) For producing the effect of doubling a distance, as in the use of reversed type in testing.

(*f*) For deflecting a beam of light for illuminating purposes.

Experiment. Hold a pin vertically in front of a concave mirror of not more than 20 cm. radius (5 D curvature),—provided the experiment is to be performed within arm's length,—and notice that when the pin is quite close to the mirror an image, *virtual* and *erect*, and very similar to that seen in a plane reflecting surface, is seen. As the pin is withdrawn from the mirror the image rapidly becomes larger and indistinct, finally fading away. Withdrawing the pin still further the image reappears, but it is *inverted*, and the size rapidly varies with the position of the pin. Keeping the pin stationary, in such a position that the inverted image is visible, place a light (a candle flame) to one side of the pin, thus forming a second object, and a piece of white paper, or other small screen, on the other side of the pin. Notice that a *real* and *inverted* image of the light is formed upon the screen, and if this were absent it would actually be formed in the air, although apparently seen in the mirror. It is an *aerial* image, and the reason why the aerial image of the pin cannot be received upon a screen is that the light from the pin is merely reflected light, and far too feeble to produce a real visible image, the surrounding light preventing the production of sufficient contrast.

There are certain terms which are used in connection with mirrors of this description. The distance apart of the edges used is called the *aperture* of the mirror, and the centre of the curved portion is known as the *pole* or *apex*. Further, an imaginary straight line joining the centre of curvature of the mirror with the geometrical centre of the curved part (pole or apex) is termed the *principal* or *optic axis*.

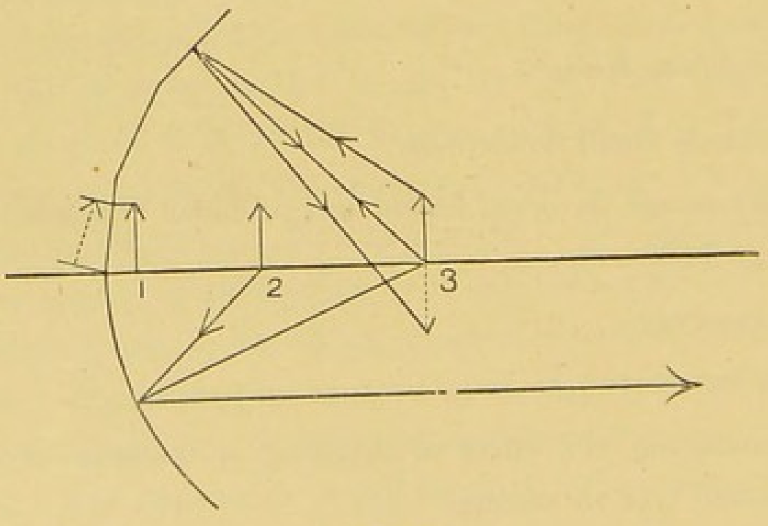


Fig 12

To explain the formation of the virtual erect image we may imagine the mirror to consist of an infinite number of plane surfaces, Fig. 12 showing three only for the upper part. Each of these is capable of producing a virtual and erect image (as explained in Chapter II.) identical in position behind the mirror with the object in front. As the object is moved from the mirror more of these supposed innumerable facets take up the reflection for the eye to view, and so the image increases rapidly in size until the object arrives at No. 2 position in the diagram, midway between the mirror and its centre of curvature. At this point the paths (rays) of light emanating from every point of the object are reflected along nearly parallel lines and so completely fill the view, the image seeming to fade away.

Let us now pass to the position marked No. 3, the centre of curvature of the mirror. The paths from this point on the axis will be reflected upon themselves from every part of the mirror, but as a part of the object is above the axis, it is evident that by making the angle of reflection equal to that of incidence for all of the supposed innumerable facets, the reflection of that part of the object will appear below the axis, the convergence of all the paths to that point forming a real image, and from the position, inverted.

As the object passes from No. 2 to No. 3 position the image decreases from an infinite size to that of the object, gradually taking form in an inverted position. No 3, it will be noticed, has a point exactly at the centre of curvature, so that all paths from that point are reflected upon themselves, forming normals to the supposed facets. The position of the image of the top of the object is thus readily understood by the construction shown.

Waves of light from an infinite distance undergo a change upon meeting the mirror such that after reflection they are twice the curvature of the mirror itself, and thus converge to point No. 2 which is termed the *principal focus*, so that the convergence or focal power of a mirror is twice its curvature, and our experimental mirror of 5 dioptres curvature has a convergence or focal power of 10 dioptres.

Consideration of the path from the point of the object at No. 3 in Fig 12, and also of that reflected to the point of the image, show that they are radii of the incident and reflected wave fronts respectively, and that they mark the direction in which these travel, just as in the lower part of the diagram the path parallel to the axis and that from the principal focus indicate the same.

These points of object and image are termed *conjugate* points, because light diverging from one converges to the other, and in the particular instance taken (No. 3), it will be noticed that object and image are at the same distance from the mirror, are alike in size, but are reversed in position, the image being inverted. If instead of the object being above the axis it were bisected by it, object and image would be coincident but reversed, and this position, viz., the centre of curvature, is the only one where such coincidence could occur. As the object approaches the mirror, so the image recedes from it, and becomes larger and larger, until the object gets to the principal focus, when the image is at an infinite distance. Movement within this point produces an image in a position which we may describe as beyond infinity, that is on the other side of the mirror, upright and virtual in character, which gradually lessens until object and image coincide at the surface of the mirror itself.

For any given *position* of the object upon the principal axis there is a given *position* for the image, and these points are known as *conjugate foci*, the conjugate point for the principal focus being at infinity. These points are interchangeable for object and image, although the object cannot in practice be placed where the virtual image is, as it would not be reflected if behind the mirror. This relation is known as the *Law of Conjugate Foci*, and applies also to direct *refraction* through a lens.

Unfortunately, when dealing with spherical mirrors, the expressions "principal focus" and "focal length" are not quite so definite as the above explanation would imply, and a glance at Fig. 13 shows why this is so.

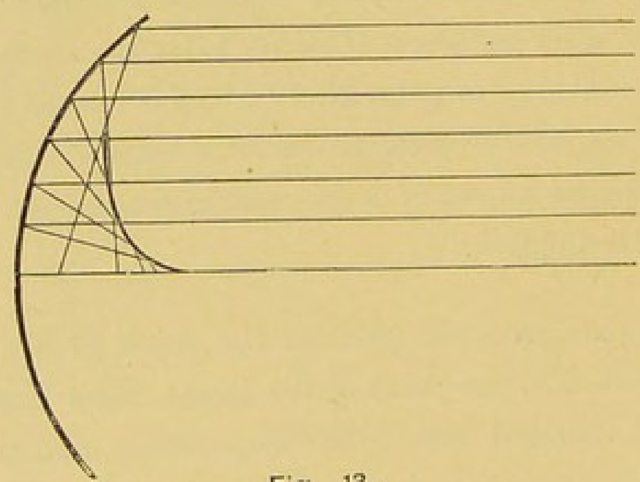


Fig. 13.

The parallel waves of light (the direction of which is represented by straight lines), coming from an infinite distance, strike each facet of which we supposed the mirror to be formed, and, following the law of reflection, cut the axis at very different points, in fact they envelop a surface called *the caustic*, and the curve indicated is therefore a caustic curve. It must suffice here to mention that the excess in bending, or curvature, of the peripheral parts of the waves of light gives rise to *astigmatism by reflection*, a condition in which the focus does not consist of a point or circle, but of two lines, really forming two line foci. This causes such distortion as to prevent the use of these mirrors in many cases. It is worthy of note that no distortion of image occurs when the object is at the centre of curvature.

Parabolic mirrors are employed when parallel light is to be brought to a focus, or when a parallel beam is required from a point of light. The parabola is obtained by cutting a cone by a section parallel to one of its sides, and is really an ellipse with one of its foci at infinity. The geometrical property of the parabolic curve is that it always satisfies the second law of reflection, and at the same time converges all portions of incident plane waves to the same point on its axis (Fig. 14). Mirrors of this type are of great service in practice.

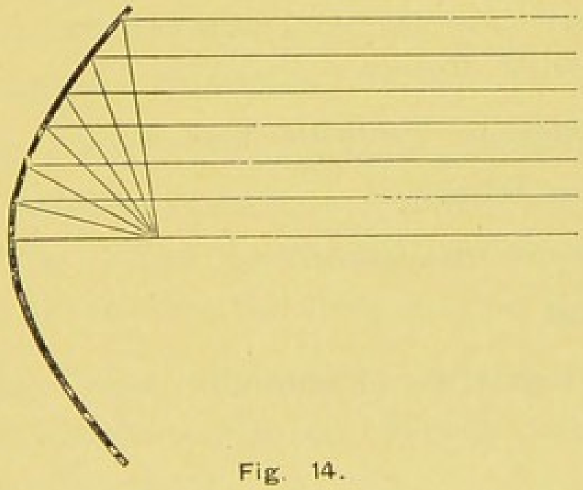


Fig. 14.

Convex mirrors do not lend themselves very extensively to practical use, and unless light is artificially made convergent before it reaches the mirror, they cannot produce a real image. Under ordinary conditions some form of virtual erect image of reduced size will be seen, and the paths of the waves of light may be traced in a similar manner to what has been done in a concave mirror, the reflected paths being produced backwards to form the virtual image.

To graphically demonstrate the formation of any image, real or virtual, by a curved surface, it is only necessary to consider that cone of light the limits of which are given by a line from the top of the object, passing through the centre of curvature of the surface, and a line from the same point of the object, running parallel to the axis until it meets the curved surface. (Fig. 15.)

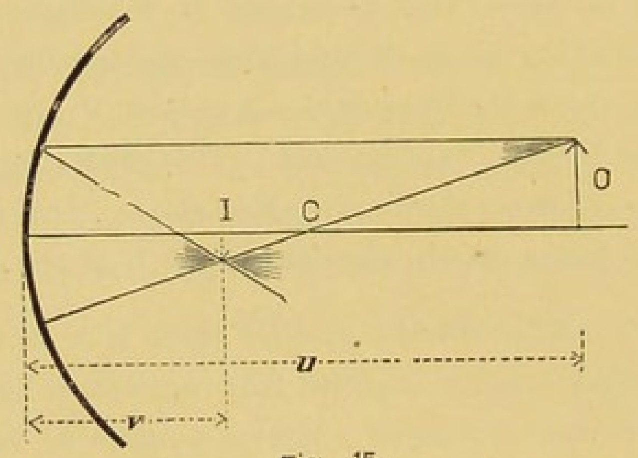


Fig 15.

It will be seen that for size of image and object the concave mirror may be likened to a pinhole camera with the pinhole at the centre of curvature, and Fig. 15 shows that the relation in size will also be equal to the ratio of the convergences of the incident and reflected light with respect to the mirror, although it must be noted that incident light is *actually* divergent.

Practical Use of Curved Mirrors.

(*a*) In the Retinoscope, Ophthalmoscope, &c.

(*b*) In Reflecting Telescopes.

(*c*) For Microscopic Illumination.

(*d*) As Reflectors.

(*e*) As Search Lights, &c. (Parabolic).

CHAPTER IV.

REFRACTION AT PLANE SURFACES.

WHEN light is incident upon a transparent medium, besides that amount which is reflected, according to the laws laid down in Chapter III, a certain portion enters the new medium, and should it be incident obliquely to the normal at the point of incidence, it is refracted, or bent out of its original path.

Experiments.

(1) Hold a pencil obliquely, and immerse half of it in water; note that the half under water appears bent with respect to the part above. (Refraction.)

(2) Hold a piece of thick plane glass in front of one eye, look through and over it at the same time, and note that on tilting it objects are apparently moved. (Deflection).

(3) Place a coin in a thin glass, and fill the glass with water to the brim. Put the glass on a table with another coin by the side of it, looking down at both coins. Note that the one seen through the water appears much nearer to the eye than that lying upon the table. (Displacement).

(4) Take a prism with a large angle (a right-angled one), and note that it is possible to view an object by *internal* reflection at one surface. (Total Reflection).

It has been mentioned that light is a motion in an unknown substance termed *ether*, the particles of which vibrate in a transverse direction to that of propagation, and that the many secondary waves set up destroy each other by mutual interference, so that the *grand* or main waves of light alone are what we need consider. Call a portion of such a main wave B C (Fig. 16), and let it meet a transparent piece of glass obliquely with respect to the plane surface. We wish to determine graphically in what manner and to what extent the course of the light is altered. In the first place we must think of monochromatic light, for then there will be but one change of velocity. Light of any colour moves at the same rate in ether or air, but so soon as light enters a medium such as a transparent piece of glass the rates of propagation of the different coloured lights vary one with another.

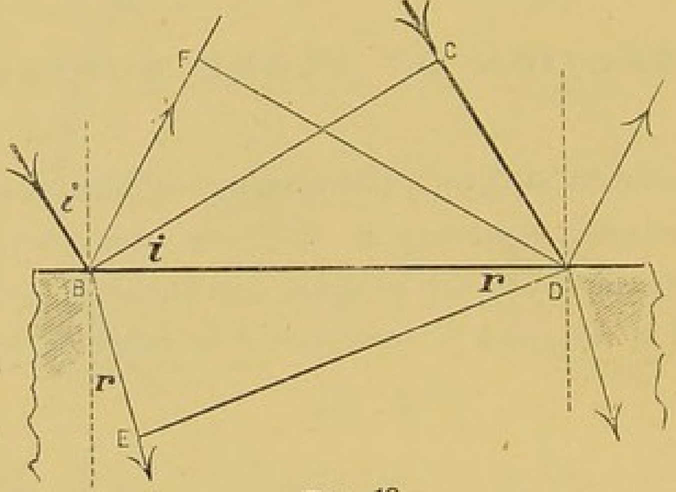


Fig. 16.

In the figure let the angle of incidence $i = 30°$, and the refractive index n_2 of the glass for certain monochromatic light $= 1·5$. Taking the refractive index of air as unity, this means that the light will travel only $0·6\dot{6}$ times, or two thirds its rate in air. Thus its speed is retarded upon entering the glass, for as was shown in Chapter II $\frac{n_2}{n_0} = \frac{V_0}{V_2}$. It follows, therefore, that to obtain graphically the refracted path of the waves of light, we have simply to strike an arc from B such that its radius is equal in value to two thirds C D, drawing a tangent to this arc through D, which will give us the position of the wave of light E D in the glass.

Since we know from our second law of refraction that—

$$\frac{n_2}{n_0} = \frac{\sin i}{\sin r} \text{ or that } \sin r = \sin i \ \frac{n_0}{n_2}$$

$$\therefore \sin r = \frac{0·5000 \times 1}{1·5} = 0·33\dot{3} \text{ (see table of sines at end of book.)}$$

$\therefore r = 19° \ 30'$. Which acts as a check upon the above construction.

Besides the light entering and refracted by the new medium, a certain percentage is reflected at the surface of separation of the two media according to the laws of reflection, and will therefore occupy a position F D, when the refracted wave occupies the position E D. It will be noticed that the effect of retardation, or slowing down of the light in the glass, is to give it an entirely new direction of propagation. The explanation of the experiment, in which the pencil held obliquely in water appears bent, is that light coming from the pencil and entering the eye is bent out of its original course at the surface of separation, hence we see that part of the pencil under water in an incorrect position.

With reference to experiments 2 and 3, we may note that when the apparent movement of an object, due to refraction, is (for all practical purposes) a lateral one, it may come under the heading "Deflection," and when the apparent movement is a compound one, or a purely vertical one, it may come under the heading of "Displacement." This nomenclature will be found convenient in practice.

It is well to note that although waves of light are merely deflected by passing through a plate of glass with parallel surfaces, the deflection depends upon the thickness of the plate, being proportionate to it.

Before considering experiment 4, it is necessary to study the refraction of light by a prism, which may be defined as a transparent solid, two of whose faces at least are plane surfaces intersecting in a line.

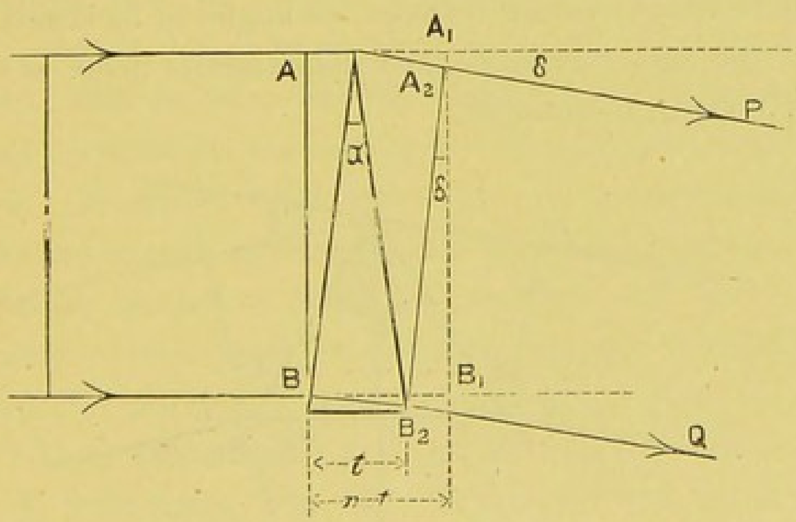


Fig 17.

In the case of a thin prism Fig. 17, with a zero thickness at its apex, and a thickness t at its base, we see that while the point A of the wave of light is only retarded for a very short period, the point B is retarded considerably, and therefore by the time A reaches A_2, B will only just be emerging from the prism at the point B_2. Had the prism not been in its path the wave would have occupied the position A_1 B_1. The amount of bending does *not* depend upon the thickness of material traversed, for A_2 P is parallel to B_2 Q, but upon the *change in the velocity*, or rate of propagation of the wave. The angle α, made by the intersection of the two faces through which the light passes, is termed the *refracting angle* ; while the angle δ, made by the incident and refracted waves (that is, the old and new paths) is termed the *angle of deviation*. Now the amount by which the wave is retarded depends upon the refractive index n_2 of the prism. If $n_2 = n_0$ then the point B_2 would be coincident with B_1 and no refraction would take place. It follows therefore that :—$BB_1 = n_2 t$

$$\therefore B_2B_1 = n_2 t - t = (n_2 - 1)\,t$$

But angles are proportional to their arcs standing on the same radius. Therefore, for thin prisms (whose refracting angles do not exceed 10°), we may take the chords B B_2 and B B_1 as being equal in length to their corresponding arcs, with a sufficient degree of accuracy, and may therefore substitute δ for B_2B_1, and α for t. By so doing we obtain the important relation, which holds good for *thin* prisms only, $\delta^\circ = (n_2 - 1)\,\alpha^\circ$.

Refraction by a Thick Prism.

The refraction of light, and particularly of plane waves, through a thick prism may be put to practical use in many ways, so that it is advisable to study the relations existing between the angles of incidence, refraction and deviation, the refracting angle, and the refractive index of the transparent substance under consideration.

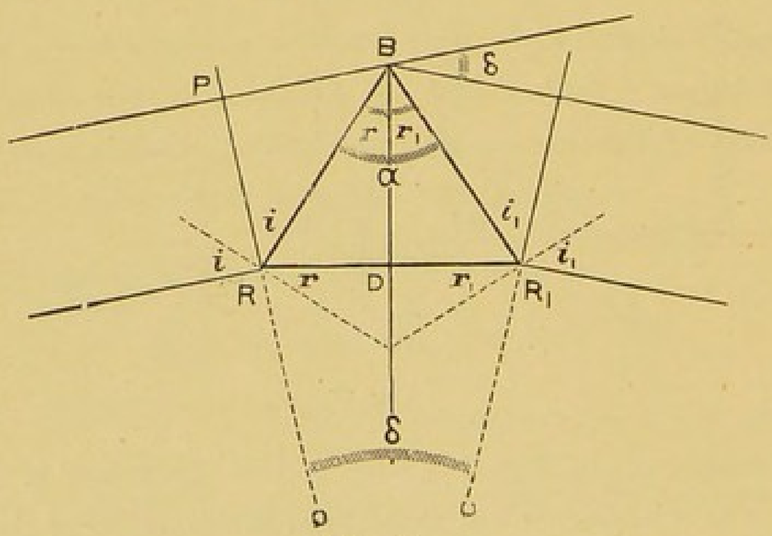


Fig. 18

In Fig. 18 is shown a section of a prism in the plane of the paper, to which the faces are supposed to be perpendicular. If we consider the portion P R of a plane wave incident upon the face R B at an angle i, then as the whole of this portion of the wave comes under the influence of the prism, by the time the point P has arrived at B, the point R will only have reached D, as its speed has been reduced, and the wave P R occupies the position B D in the prism. Upon emerging the wave is again bent away from its original path, for it enters a medium of less refracting power, and therefore its path makes a greater angle (i_1), with the normal to the second surface than what it did (r_1) upon meeting that surface. The angle through which the light is deviated is therefore δ, known as the *angle of deviation*. The angle a, made by the intersection of the two faces of the prism, is the *refracting angle*. The angle r_1 is the angle of refraction for light retracing its path, and we see from the figure that the refracting angle is equal to the sum of the angles of refraction. That is :

$$r + r_1 = a \qquad (1)$$

Also i and i_1 are the exterior angles of the triangles R B Q and R_1 B Q respectively, therefore

$$i + i_1 = \delta + a$$
$$= \delta + (r + r_1)$$
$$\therefore \quad \delta = i + i_1 - (r + r_1)$$
$$= i + i_1 - a \cdot \qquad (2)$$

Experiment shows that the angle of deviation δ varies with the angle of incidence, that is, the angle at which the wave front strikes the surface of the prism ; and further, that the condition for a minimum value for δ (minimum deviation) is the same as that for symmetrical refraction through the prism. Therefore, when the angle of emergence equals the angle of incidence (and $r = r_1$), the angle δ has its minimum value. The condition for minimum deviation being symmetrical refraction, the accurate measurement of this angle of deviation becomes of considerable practical importance, for when δ is a minimum, and it is easy to tell when this is the case with an instrument for measuring angles, such as a goniometer, the wave B D produced, Fig. 18, will exactly bisect the angle δ.

Therefore $i = i_1 = \frac{a + \delta}{2}$, also

$$r = r_1 = \frac{a}{2}.$$

But the refractive index of the substance,

$$n_2 = \frac{\sin i}{\sin r} = \frac{\sin i_1}{\sin r_1}$$

$$\therefore \; n_2 = \frac{\sin\left(\frac{a + \delta}{2}\right)}{\sin\left(\frac{a}{2}\right)} \qquad (3)$$

The goniometer enables the angles α and δ to be accurately measured. Here, therefore, is an easy and accurate method of determining the refractive index of transparent substances, but we must remember that this equation (3) only holds good when the deviation is a minimum. Liquids may be made to take the required form by putting them in prism-shaped glass troughs.

A goniometer consists essentially of a collimator and a telescope mounted upon a horizontal circle, and facing a small table for holding the prism, about which they can rotate.

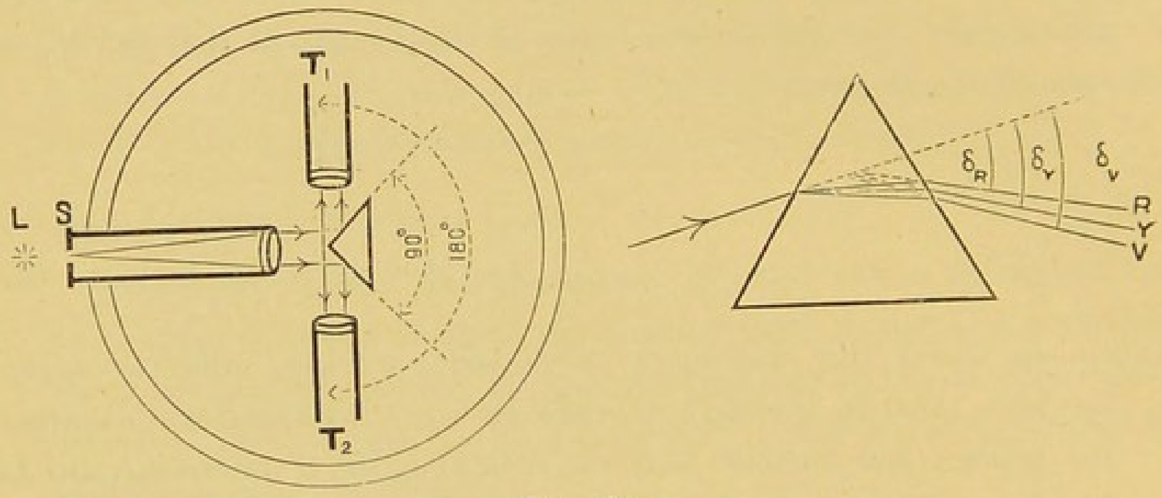


Fig. 18a.

The collimator is an instrument for producing parallel light, and consists simply of a vertical slit and a convex lens, placed at a distance from the slit equal to its focal length. The telescope is a simple astronomical one, fitted with cross-wires. To measure the refracting angle α, the apex of the prism is faced down the collimator, and the telescope first moved into position (1) and then to position (2). The angle made by the two positions of the telescope may be read off upon the graduated circle, and this angle will be just *twice* the angle α. To measure the angle δ a direct reading is taken, without the prism in position, and then, with the prism replaced as shown by the sketch annexed to Fig. 18a, a reading of the position of the telescope is taken for minimum deviation. That is when the angle δ is as small as it possibly can be for the particular coloured light. The prism itself should be rotated about a vertical axis at the same time as the telescope is moved, the slit of light in the field of view of the telescope being always kept in sight. α and δ in formula (3) should then be replaced by their respective values and the refractive index n worked out. A good instrument will give it correct to the fourth decimal place, with care

From the diagram it will be noticed too that the angle δ increases as the *time period* for the light decreases, so that the angle δ is greater for violet than red light. Hence the refractive index will be greater for violet than for red light for the same piece of glass.

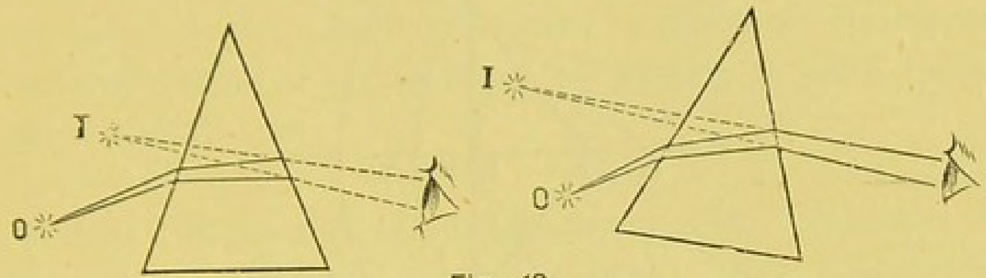


Fig. 19.

Fig. 19 illustrates vision of an object through a prism, and the effect of movement of the prism upon the position of the image. All waves emanating from O and meeting the prism surface will be spherical ones, and in each case the section of a small cone of light is shown, the first figure giving the position for minimum deviation, and the dotted lines indicating the direction in which the image is seen.

In the second figure the object and eye are in precisely the same places, but the prism has been so tilted that the base is nearer the object. Not only is the deviation greater, but the image has suffered displacement, being further away, and the visual angle is smaller, which always causes the image to appear smaller. These effects are more pronounced as the angle of the prism increases in size, and as the position of minimum deviation is departed from in either direction.

We may thus see, that as the base of a prism is turned towards an object and the apex away, so the object appears to decrease in size, and as the base is turned away, so it appears to increase in size. Other phenomena, due to dispersion, observed when looking through a prism, are dealt with in Chap. VI.

Refraction of a Spherical Wave at a Plane Surface. In Fig. 20, let a divergent spherical wave of light, proceeding from the point O, meet the plane surface of a block of more highly refracting transparent substance. That portion B, which meets the surface of separation first, will come under the influence of the more highly refracting medium first, and therefore be retarded by a certain amount before any other portion. Hence, by the time the whole wave A B C is in the second medium, its shape will be altered. If the new medium had not been encountered the wave would at some instant have occupied the position shown by the dotted lines of the curve.

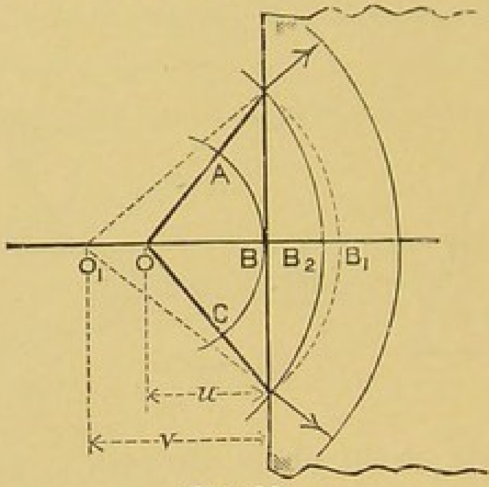


Fig. 20.

As, however, the new medium retards the wave, it becomes flattened, and appears to be proceeding from the new centre O_1. If, then, $B B_1$ represents the velocity of the wave in the first medium, $B B_2$ represents the velocity in the second.

But $\frac{n_2}{n_0} = \frac{V_0}{V_2}$ and $n_2 = \frac{V_0}{V_2}$ when n_0 equals unity, as for air.

Therefore $n_2 = \frac{B B_1}{B B_2}$, or $B B_1 = n_2 B B_2$; an important relation.

The path of the wave which meets the surface normally is not refracted. The refracted wave will really form a hyperbola, but we may consider it as the portion of a sphere. If r_1 and r_3 denote the radii of the incident and refracted waves, then :—$n_0 r_3 = n_2 r_1$. (but $n_0 = 1$)

$$\therefore r_3 = n_2 r_1. \qquad (4)$$

Thus the radius of the refracted wave is n_2 times the radius of the incident wave. Or, denoting O B by u and O_1 B by v, we have :—

$$v = n_2 u.$$

Suppose that the incident wave had been plane, or, secondly, that the surface had been a spherical one, with centre at O. In neither case would any refraction take place, for in both cases all points of the incident wave would come into contact with the new medium simultaneusly (and therefore normally). The rate of propagation would be altered of course, and so the wave would be retarded; but since all points of the wave would be retarded to the same degree, no alteration in the shape of the wave would take place, and consequently there would be no refraction.

We have seen how curvature can be expressed in dioptres (Chap. I.) and curvature was shown to be the reciprocal of its radius, in metres. We may follow the effect of refraction, therefore, through any number of media, with any number of surfaces—curved or otherwise—and all we need do is to add and subtract, noting the change undergone in the shape of the wave at each successive refraction, in order to determine the curvature of the final emergent wave, and therefore the position at which the wave is brought to a focus.

Total Reflection. Experiment 4, described previously, illustrates a very important phenomenon—that of total reflection. This only takes place when light impinges upon a medium of less refractive index. In Fig. 21

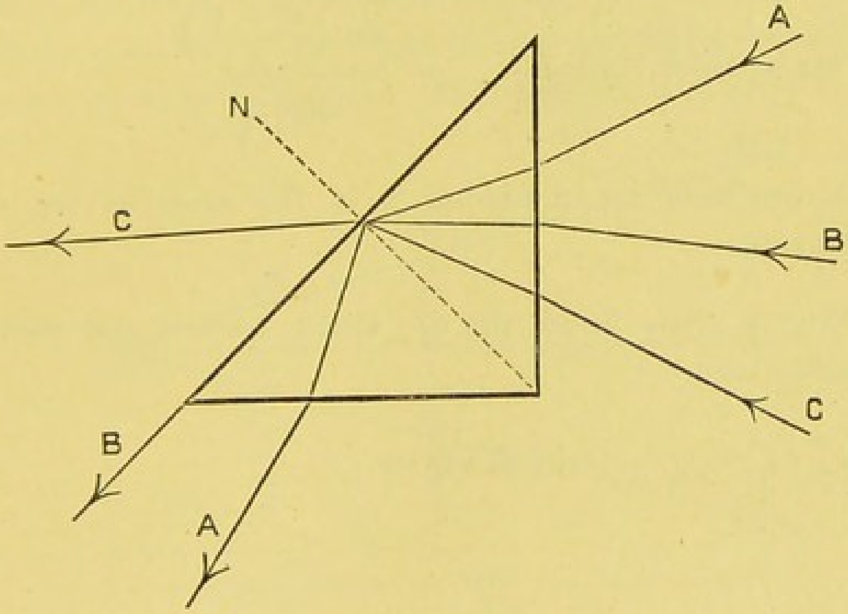


Fig. 21.

three paths of light are shown passing into a prism, the paths indicating the direction of march of the wave fronts. When they arrive at the long side of the prism, their various paths become quite different, for the one is refracted into air, the second is deflected along the boundary, while the third is totally reflected, in accordance with the laws of reflection. In the case of the second path, the angle which this makes with the normal is known as the *critical angle.* If we reverse the path, then the angle of incidence in air is 90°, and sin 90° = 1. But when $n_0 = 1$, $n_2 = \frac{\sin i}{\sin r}$, therefore when $i = 90°$ in air, $n_2 = \frac{1}{\sin c}$, which is unity divided by the sine of the critical angle. Conversely, if we know the n of a substance we can calculate the value of its critical angle.

Right angled prisms are used in various instruments to obtain total internal reflection, and it will be observed that the images so obtained will be inverted.

Herewith are given the refractive indices and critical angles of three substances, which should be verified by use of the above formulæ.

Water	$n = 1{\cdot}33$	Critical angle $48^\circ{\cdot}34'$.
Crown glass	$n = 1{\cdot}51$	„ $41^\circ{\cdot}14'$.
Flint glass	$n = 1{\cdot}53$	„ $40^\circ{\cdot}46'$.

Summary.

(*a*) In refraction by a thin prism $\delta^\circ = (n_2 - 1)\ \alpha^\circ$

(*b*) With a thick prism $n_2 = \dfrac{\sin\left(\dfrac{\alpha^\circ + \delta^\circ}{2}\right)}{\sin \dfrac{\alpha^\circ}{2}}$

(*c*) The condition for minimum δ is the same as for symmetrical refraction.

(*d*) Tilting a prism before the eye alters the size and position of the image seen.

(*e*) $n_2 = \dfrac{1}{\sin c}$ (critical angle).

CHAPTER V.

MIRROR AND THIN LENS PROBLEMS.

WE have seen that light consists of a wave motion in the ether, and we may represent it diagrammatically, in section, by concentric circles, as shown in the diagrams; but what is more important, we can definitely state the *dioptric power of the light* at any particular moment, provided we know the position of the point from which it diverges, or to which it is converging. The dioptric power of the light at any particular instant is the wave curvature expressed in dioptres. For example, in Fig. 22, A is a source

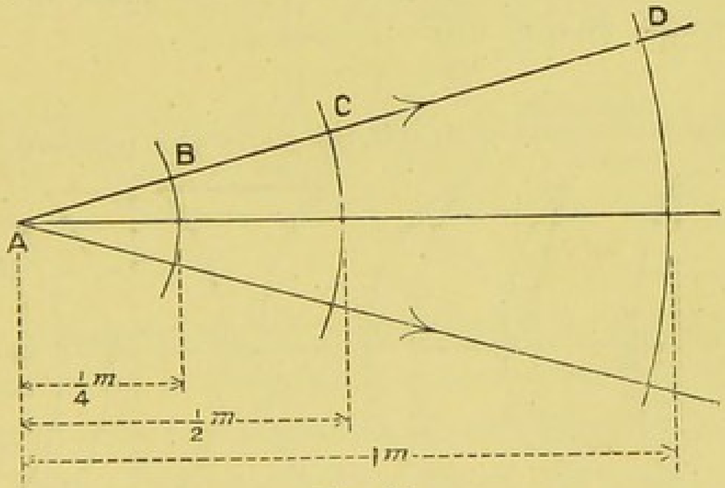


Fig. 22.

of light, and since light is a wave motion, at $\frac{1}{4}$ metre distance we may represent the light by the wave B, at $\frac{1}{2}$ metre by C, etc. The radius of the wave in linear measurement does not immediately convey to our minds its curvature, hence we have resource to the unit of curvature, the dioptre. The imaginary wave with a radius of one metre we say has a *power* of one dioptre, and as the radius decreases, so the curvature of the wave correspondingly increases, and vice versâ. When, therefore, the radius is $\frac{1}{4}$ metre (25 c.m., 10 inches) the curvature of the light wave is given by *4 dioptres*. Thus the power in dioptres is the reciprocal of the radius in metres, and in a similar manner all spherical surfaces may have their curvature defined. A lens, for instance, has two curved surfaces, R_1 and R_2; if R_1 and R_2 have equal radii (r_1 and r_2), each $\frac{1}{5}$ metre (20 c.m.)

in length, the curvature of each surface is equal to 5 dioptres. Again, the change in curvature (alteration in the shape of the wave of light) due to reflection or refraction may obviously be expressed by another curve, as has already been shown. This curve is termed F, and when expressed in dioptres represents the reflecting or refracting power, as the case may be, of the system under consideration. F is therefore known as the *focal-power* or *convergence* of the system. The reciprocal of F, in dioptres, gives the focal length, *f*, of the system, in metres. This F is the algebraic sum of the incident and reflected, or emergent, curvatures of the wave, and denoting the incident curvature by U and the reflected or emergent one by V we see that F is equal to the sum of U and V when U and V are curved in opposite directions, and the difference of U and V when U and V are curved in the same direction. F therefore is equal to V + U, or V − U, or U − V, according to circumstances. If, however, we decide always to treat divergent curves as negative and convergent curves as positive, we may write once for all

$$F = V - U,$$

and re-arrange this equation to suit the particular problem we wish to solve.

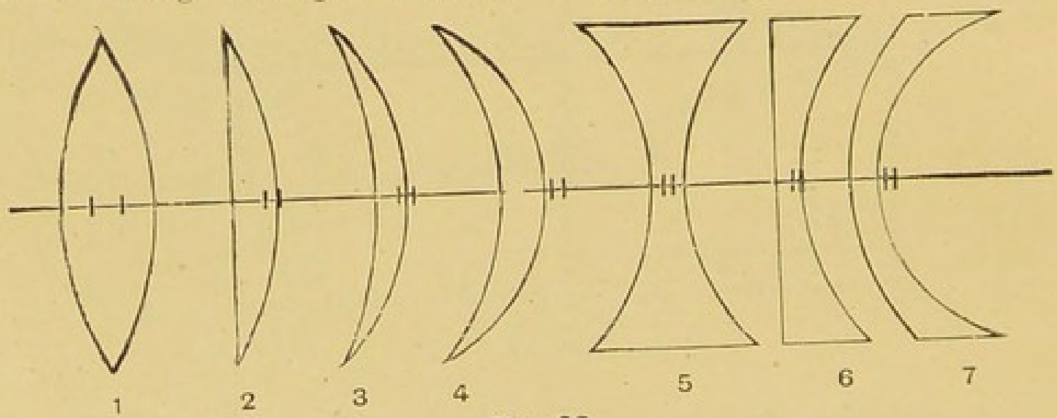


Fig. 23.

1. Double convex. 2. Plano convex. 3. Periscopic convex. 4. Deep periscopic convex. 5. Double concave. 6. Plano concave. 7. Deep periscopic concave.

In Fig. 23 names are given to the various types of lenses shown, which represent the chief forms in use. The focal power or convergence does not depend upon the shape of a lens, but upon its total refracting power, and two lenses may vary widely, so far as shape is concerned, and yet have the same focal power—producing the same change in curvature upon the wave of light.

The Principal or Optic Axis of a Mirror is the imaginary line, produced if necessary, joining the centre of curvature of the mirror and the geometrical centre of that portion of the mirror under consideration.

The Principal Axis of a Lens is the imaginary line, produced if necessary, joining the centres of curvature of the two surfaces.

Optical Centre. The optical centre is that point upon the principal axis through which pass all waves which have their paths parallel before and after reflection or refraction.

The Optical Centre of a Mirror. From the above definition of an optical centre it follows that the optical centre in this case is coincident with the centre of curvature of the surface.

The Optical Centre of a Lens. In practice one requires to deal with this imaginary point from two separate positions; first, directly from the front; and secondly when the lens is seen in section—edgeways. For convenience we may term the first, the *direct optical centre*; and the second, the *sectional optical centre*. Then we have—

The Direct Optical Centre is that point at which the principal axis cuts the lens.

The Sectional Optical Centre is that point on the principal axis at which the imaginary line joining two parallel radii at the points of contact with their respective surfaces cuts it. (This satisfies the definition of *the* optical centre as above defined.)

The method for determination of the position of the direct optical centre of a lens in practice is to hold it in front of the eye so that two cross lines, such as are formed by the bars of window panes, are in perfect alignment outside and within the lens when viewed through it. The point of intersection of the lines as seen through the lens is the direct optical centre. The cross lines, whether upon a white card placed horizontally, or as window bars in a vertical plane, must always be in a plane parallel to that in which the lens is held.

The graphical determination of the position of the sectional optical centre is seen in Fig. 24 (I. and II.). C and C_1 are the centres of curvature of the surfaces, and any two radii C B and C_1 A are drawn parallel to each other. B and A are joined, and in (I.) where this line cuts the principal axis is the position of the optical centre. In (II.) it is necessary to produce B A along the path of the wave outside the lens, according to the law of refraction, C_1 A being the normal to the first surface. Similarly in (I.) we may trace this, and also the path of emergence B E, and in all cases D A and B E must be parallel.

The deviation of the path will be represented by d, and is exactly similar to that caused by an equivalent rectangular block of glass P Q R S, of thickness t.

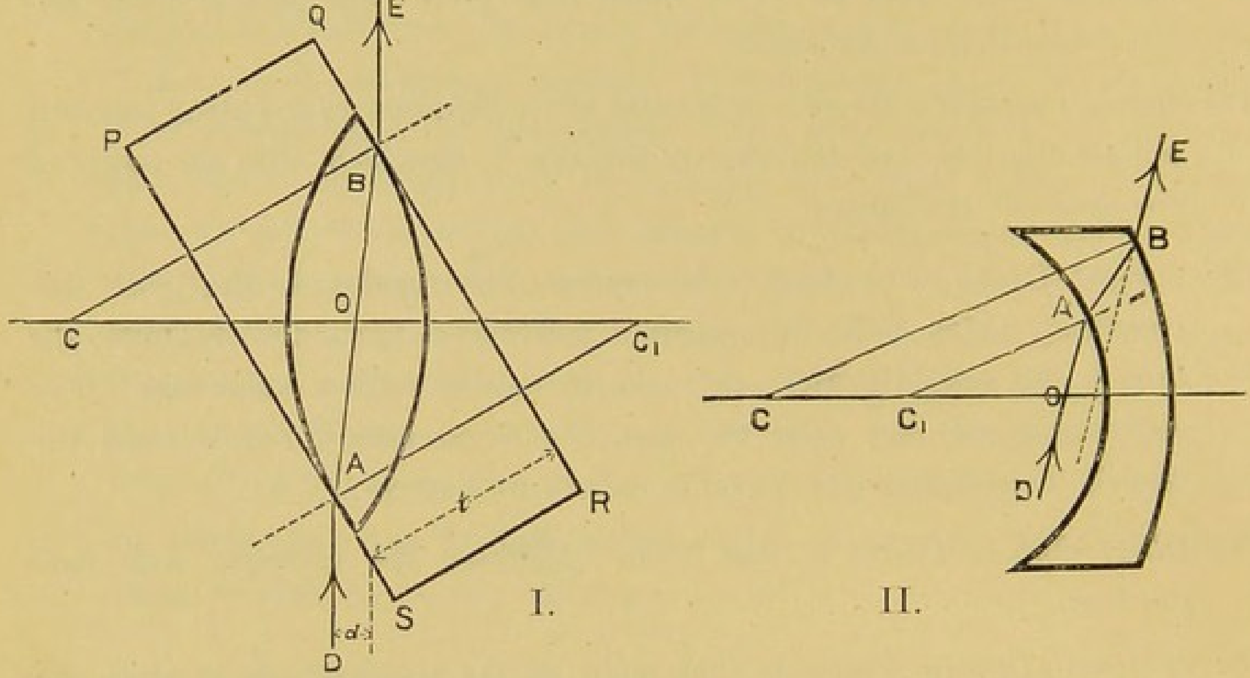


Fig. 24.

We are now in a position to investigate two important fundamental formulæ applicable to both spherically curved mirrors and thin spherical lenses, remembering the notation adopted in Chapter I.

In Fig. 25 (I., II., III., IV.), in each case let U represent the curvature of the incident wave (incident curvature), that is, the curvature of the wave of light just as it comes into contact with the reflecting or refracting surface; then u, the radius of curvature of the incident wave is called the *first conjugate distance*. By reflection or refraction, as the case may be, the curvature of the wave is altered, and the new form will be complete when the last portion of the wave has just been reflected or refracted. At this moment the curvature of the wave V is called the emergent curvature; then v, the radius of this curve, will represent the *second conjugate distance*. These are the true conjugate distances, if we define them as being the radii of the incident and reflected, or emergent, waves. In practice, however, it is convenient to measure both u and v from the geometrical centre of the mirror surface, or from the optical centre of the lens (not shown in III. and IV.), for these are points whose positions may be determined with great accuracy. Moreover, by denoting the curvature which the incident

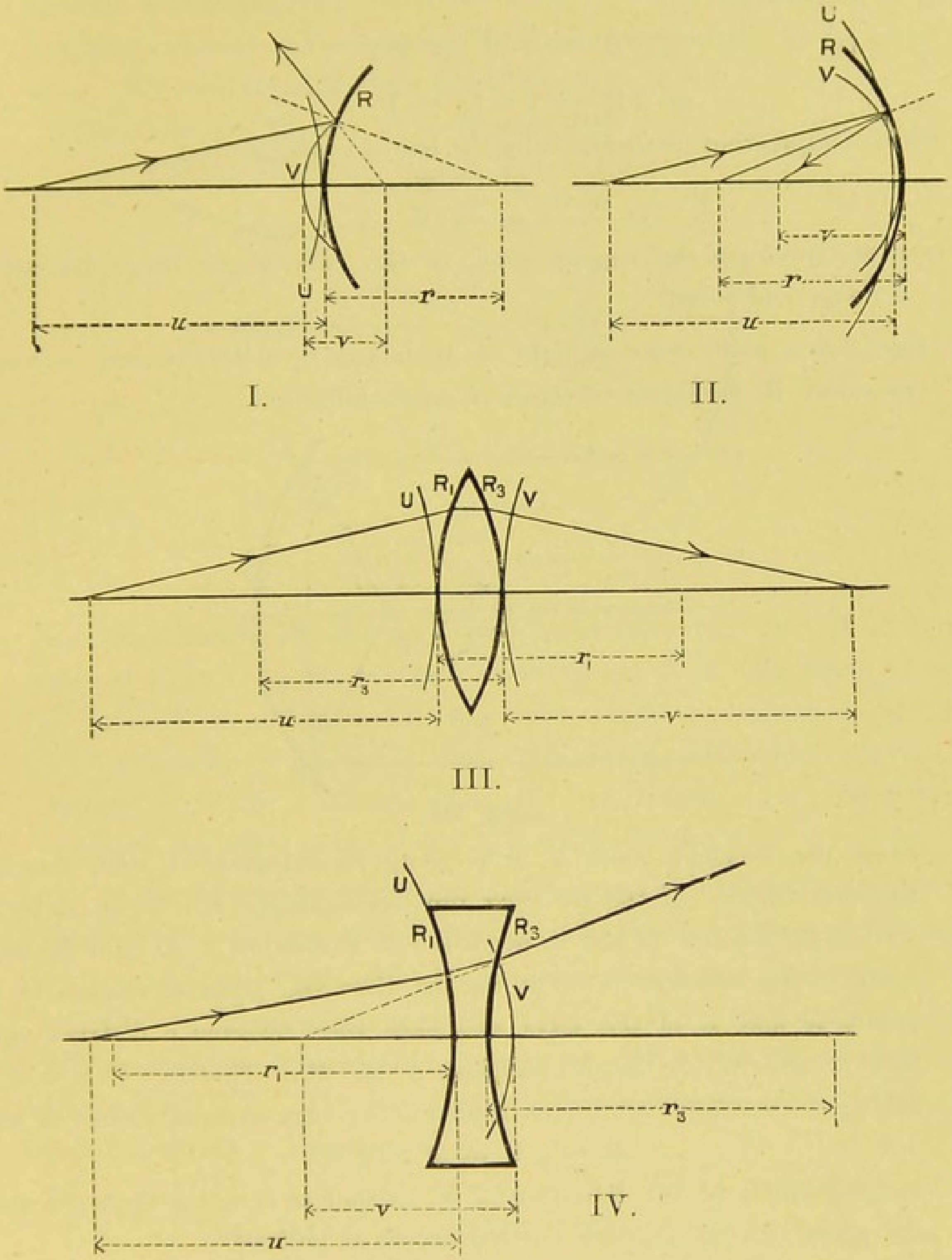


Fig. 25.

wave would have, at the mirror surface, or optical centre of a lens, as the incident curvature, and the curvature that the emergent wave would have at the mirror surface, or optical centre of a lens, the emergent curvature, the relations which exist between these curves and the other factors in mirror and lens problems can be expressed, mathematically, in a simple manner.

Mirror Formulæ :

(1) $$R = \frac{V-U}{2} = \tfrac{1}{2} F$$

$$\text{or } 2R = V - U = F$$

A relation expressing mathematically the law of conjugate foci.

(2) $$m = \frac{v}{u} = \frac{U}{V}$$

Where m represents the *magnification*, or the ratio of the linear dimensions of image and object.

In Fig. 25a a plane wave of light A B, falling upon the concave mirror of curvature R, receives a curvature V upon reflection.

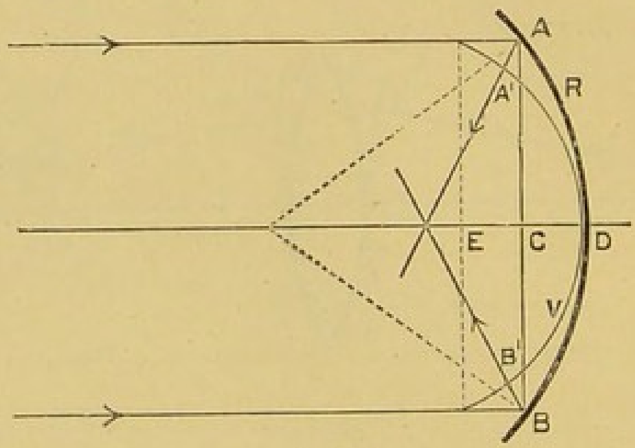


Fig. 25a.

Since the incident wave A B is plane its curvature U = O, therefore the curvature V of the reflected wave is equal to F. Upon incidence the centre portion of the wave A B has a distance C D still to travel before being reflected, so that by the time the point C reaches D the points A and B of the wave will have been reflected a distance equal to C D and will be in the positions A′ and B′. Therefore C E = C D, and since curvatures are proportional to their sags on equal chords we have

$$R = \tfrac{1}{2} F \text{ or } F = 2R$$

but according to our definition of F, as well as from the figure, treating divergent light as negative and convergent as positive,

$$F = V - U$$

$$\therefore 2R = V - U$$

Whatever the curvature of the incident wave, that of the reflecting surface must be the mean between the curvatures of the incident and reflected waves, or :

$$R = \frac{V-U}{2} \quad \text{and therefore}$$

$$2R = V - U = F$$

Concave mirrors produce convergent waves, or less divergent ones than the original; whereas convex mirrors produce divergent, or less convergent ones. We have therefore with light from L to R

a. Concave Mirrors $-R$ and $+F$

b. Convex Mirrors $+R$ and $-F$

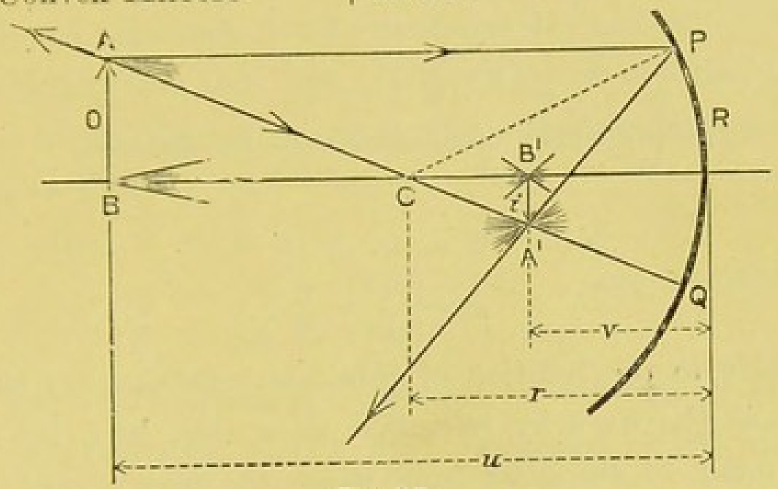


Fig. 26.

The magnification formula may be deduced from Fig. 26. A divergent cone of light from the point A of an object A B falls upon a mirror of curvature R, and is transformed into a cone converging to the point A^1. Similarly a divergent cone from B is transformed into a cone converging to B^1. In the plane $A^1 B^1$, therefore, a perfect representation, the *image* of the object A B will be formed.

In order to graphically determine the position and size (magnification) of the image only two lines need be drawn from the extremities of the object, A P parallel to the axis, and A Q through the centre of curvature (optical centre) C of the reflecting surface. The line A P, representing a path, will be reflected along A^1 P by the mirror, A P and A^1 P, making equal angles with C P. The line A Q will retrace its path, since it strikes the mirror normally. Therefore—

$$AB : A^1B^1 :: BC : B^1C$$

$$\text{but } BC = u - r \text{ and } B^1C = r - v$$

$$\therefore BC : B^1C :: u : v$$

Calling A B, o; and $A^1 B^1$, i, we have :—

$$o : i :: u : v;$$

but by definition $m = \dfrac{i}{o}$

$$\therefore m = \frac{v}{u}, \text{ and since } v = \frac{1}{V} \text{ and } u = \frac{1}{U}$$

$$\therefore m = \frac{U}{V}.$$

Therefore we see that the magnification is given by the ratio of the curvatures (in dioptres) of the incident and reflected waves.

From the equations

(1) $$F = 2R = V - U$$

$$\text{or } \frac{1}{f} = \frac{2}{r} = \frac{1}{v} - \frac{1}{u}$$

(2) $$m = \frac{v}{u} = \frac{U}{V}$$

the whole of the properties of mirrors may be deduced.

The equations

(1) $$F = V - U$$

and (2) $$m = \frac{v}{u} = \frac{U}{V},$$

are applicable to the solution of thin lens problems, but the alteration in the shape of the wave by refraction at a thin lens depends upon the refractive index of the glass from which the lens is made. For lenses therefore we must not write

$$F = V - U = [2R].$$

Calling the curvatures of the two surfaces of the lens R_1 and R_3, the refractive index n_2, and the refractive index of the surrounding medium n_0, the relation existing between these quantities and the focal power F is given by the equation—

$$F = (n_2 - n_0)(R_1 - R_3).$$

If the surrounding medium is air $n_0 = 1$, and we may therefore write :—

$$F = (n_2 - 1)(R_1 - R_3) \qquad (3)$$

$$\therefore V - U = (n_2 - 1)(R_1 - R_3) \qquad (4)$$

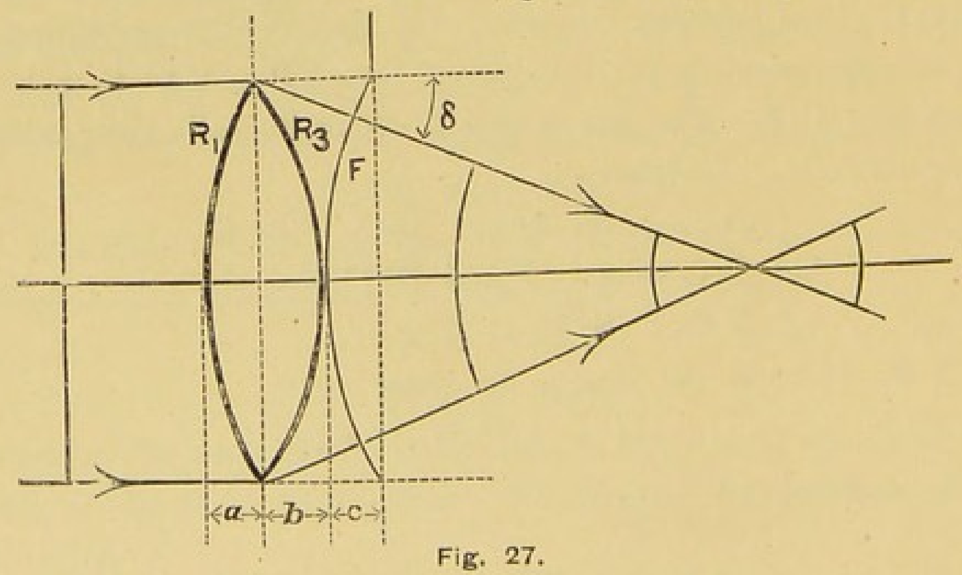


Fig. 27.

In this figure $t = a + b$

and $n_2 t = a + b + c$

$\therefore (n_2 - 1) t = c$

In Fig. 27 let t denote the thickness of the convex lens L, a the sag corresponding to the curvature of its first surface, b the sag corresponding to the curvature of its second surface, and c the sag corresponding to the curve F, which represents the change undergone in the curvature of the wave, that is, the focal power of the lens. Then t represents the sag corresponding to the sum of the curvatures R_1 and R_3. Also, as in the case of refraction by a thin prism (Chap. IV.), we see that the retardation, represented by the sag c, is given by $(n_2 - n_0)\,t$. If $n_0 = 1$ this may be written $(n_2 - 1)\,t$.

$$\text{But} \quad t = a + b$$

$$\therefore \quad c = (n_2 - 1)\,(a + b), \quad \text{and consequently}$$

$$F = (n_2 - 1)\,(R_1 + R_3).$$

Remembering the rule of treating surfaces curved like divergent waves as negative, and surfaces curved like convergent waves as positive, we must write:—

$$F = (n_2 - 1)\,(R_1 - R_3)$$

having $+ R_1$ and $- R_3$ according to our convention of signs.

From the three equations

$$F = V - U \qquad (1)$$

$$m = \frac{v}{u} = \frac{U}{V} \qquad (2)$$

$$F = (n_2 - 1)\,(R_1 - R_3) \qquad (3)$$

the whole of the properties of thin lenses may be deduced.

Equation (3) may be written

$$\frac{1}{f} = (n_2 - 1)\left(\frac{1}{r_1} - \frac{1}{r_3}\right).$$

Herewith are given a few examples of mirror and thin lens problems. In each case sketches should be made by the reader for illustration.

Example (1). How far from a concave mirror, whose radius of curvature, r, is equal to 1 metre, would you place an object, to obtain a real image of three times the size?

We have $$m = \frac{v}{u} = 3$$

$$\therefore \quad v = 3\,u.$$

Also, for a concave mirror producing a real image $\frac{2}{r} = \frac{1}{v} - \frac{1}{u}$ becomes $\frac{2}{r} = \frac{1}{v} + \frac{1}{u}$ since the incident light is divergent, and therefore

u is negative. Strictly speaking we should write $-\frac{2}{r} = -\frac{1}{v} - \frac{1}{u}$ (See Fig. 25 II.)

$$\therefore \quad \frac{2}{r} = \frac{u+v}{vu} = \frac{4u}{3u^2}, \text{ since } v = 3u.$$

Putting in the value r, we have :—

$$\frac{2}{1} = \frac{4}{3u}, \text{ or } 3u = \frac{4}{2}$$

$$\therefore \quad u = \frac{2}{3} \text{ metres} = 66.\dot{6} \text{ c.m.}$$

$$\text{and } v = 3u = 2 \text{ metres} = 200 \text{ c.m.}$$

The object would therefore be placed at $\frac{2}{3}$ of a metre from the concave mirror. The image formed must be a *real* one, for the light waves after reflection are convergent, and the object is at a point on the axis between the centre of curvature and the focal point.

Example (2.) Determine the size and position of the image of an object 5 c.m. long placed 25 c.m. in front of a convex mirror, whose radius of curvature is 50 c.m.

Here $u = 25$ c.m. $\quad \therefore$ U $= 4$ dioptres

But $\frac{2}{r} = \frac{1}{f}$ (the focal length is half the radius of curvature).

$\therefore \quad f = 25$ c.m.

Also $\mathrm{F} = \frac{1}{f}$ (metres)

$= 4$ dioptres.

Since the mirror is convex, both incident and reflected light is divergent, but the reflected divergent light is curved in the direction of convergent light passing from L to R. So that in this case we have $-$ U, $+$ V, $+$ R, and also $-$ F, according to our notation. (Fig. 25 I).

Instead of F = V − U, we have − F = V − (− U).

$\therefore$ V = − F − U in this case.

$= -8$ dioptres. (The negative sign indicates a *virtual* image.)

$\therefore \quad v = \frac{1}{8}$ metres $= 12{\cdot}5$ c.m.

$$\text{Also } m = \frac{v}{u} \text{ or } \frac{\mathrm{U}}{\mathrm{V}}$$

$$= \frac{12{\cdot}5}{25} \text{ or } \frac{4}{8} = \frac{1}{2}$$

The virtual image is therefore apparently situated 12·5 c.m. behind the mirror, and is only one half the size of the object.

Example (3). An object is placed 20 c.m. in front of a convex lens which produces a real image of the object upon the other side, at a distance of 1 metre. What is the focal power of the lens, and the magnification ?

In this case, since

$$m = \frac{v}{u} = \frac{100 \text{ c.m.}}{20 \text{ c.m.}} = 5. \text{ (magnification)}$$

Also we have $-$ U and $+$ V.

Therefore F = V − U becomes

$$F = V - (-U) = V + U$$

$$u = 20 \text{ c.m.} \quad \therefore \quad V = 5 \text{ dioptres.}$$

$$v = 100 \text{ c.m.} \quad \therefore \quad V = 1 \text{ dioptre.}$$

$$\therefore \quad F = 1 + 5 = 6 \text{ dioptres (focal power).}$$

The focal length, $f = \frac{1}{F} = \frac{1}{6}$ metres $= 16{\cdot}\dot{6}$ c.m.

Which means that parallel light falling upon the lens will be brought to a focus, on the other side, at $16{\cdot}\dot{6}$ c.m., from the optical centre of the lens.

Example (4). The refractive index of a double-convex lens is stated to be 1·53, and the curvatures of its surfaces in dioptres 3 and 5 respectively. What is the focal power of the lens?

Here $n_2 = 1{\cdot}53$, $R_1 = 3{\cdot}0$, and $R_3 = 5{\cdot}0$.

Now $F = (n_2 - 1)(R_1 - R_3)$

But since the lens is a double-convex one, we have $- R_3$ because this surface is curved like divergent light passing from left to right.

$$\text{Therefore} \quad F = (n_2 - 1)(R_1 + R_3)$$

$$= 0.53 \times 8 = 4.24 \text{ dioptres.}$$

Measurement of Curvature in Practice. We often require in practice to determine the curvature in dioptres of a mirror or lens surface. This is most easily accomplished by applying to the surface an instrument, called a *spherometer*, consisting essentially of a tripod or ring, in the middle of which a vertical rod, capable of being raised or lowered by mechanical means, is fixed.

The principle of the instrument is based upon a theorem of Euclid (Book III., Prop. 35) :—

"*If two chords of a circle cut one another at a point within the circle, the product of the segments of one chord is equal to the product of the segments of the other chord.*"

Therefore in Fig. 28, $c \times c_1 = h \times m$, and $m = 2\,r - h$.

Therefore if $c = c_1$ we have

$$c^2 = h\,(2\,r - h)$$
$$= 2\,r\,h - h^2$$

From which we see that

$$\frac{c^2 + h^2}{2\,h} = r,$$

and therefore that, since $R = \frac{1}{r}$,

(5) $$\frac{2\,h}{c^2 + h^2} = R$$ (the curvature of the surface).

The spherometer is so constructed that it fulfils the conditions of the above equation. The distance from its vertical rod to the edge of the ring, or one of the tripod legs, corresponds to the distance c in Fig. 28, while a movement of the vertical rod enables the elevation (or depression), corresponding to the distance h in the figure, to be measured.

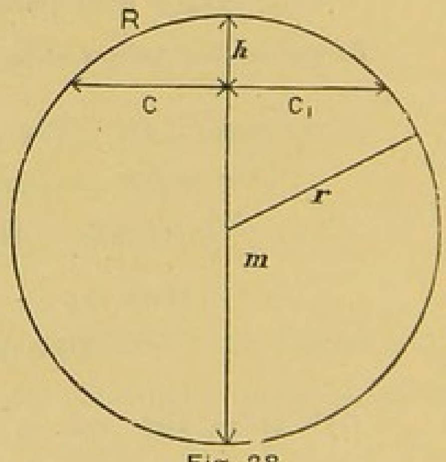


Fig 28.

The spherometer therefore gives the exact values for c and h for the surface under test. These values are then substituted for c and h in equation (5) and R, the curvature of the surface in dioptres, determined. To obtain R in dioptres the distances c and h must of course be expressed in metres.

The instrument affords an easy method of determining experimentally the focal power of a mirror, since $F = 2R$, and as, for lenses,

$$F = (n_2 - 1)\,(R_1 - R_3),$$

if we know the refractive index of the substance of which a lens is composed F is easily determined. Moreover, should F, R_1 and R_3, be known n_2 can be determined.

The "lens measure" of the optical trade has a dial attached, with the readings so arranged that the actual curvatures measured have been multiplied by ·51, *i.e.* $(n_2 - 1)$. For this purpose it is assumed that crown glass of 1·51 refractive index will be used, so than an *optically* denser material would give an incorrect reading, as in the case of flint glass or "pebble." The instrument is more convenient than accurate, because it measures the dioptric power of each surface directly.

Summary.

(*a*) F denotes focal power or convergence of a mirror, lens, or lens system.

(*b*) For Mirrors $R = \frac{V - U}{2} = \frac{1}{2} F$

$$\text{or } \frac{1}{f} = \frac{2}{r} = \frac{1}{v} - \frac{1}{u}$$

$$m = \frac{v}{u} = \frac{U}{V}$$

(*c*) For thin Lenses.

$$F = V - U = (n_2 - 1)(R_1 - R_3)$$

Chapter VI.

CHROMATIC AND SPHERICAL ABERRATION.

A SINGLE lens, producing a real image of an object, is by no means satisfactory for the purpose, and if the lens is at all powerful, that is, of short focal length, then a glance at the image on a screen will show that it is not an exact representation of the object, nor will it be possible to obtain an outline so sharply defined as in the actual object, no matter where the screen is placed. Moreover, if it is held rather inside what is considered to be the best focus, and the luminous object is giving out composite light (white light), then the image is found to be surrounded by a red haze; likewise, if the screen is held a little outside the best focus, then the image is found to be surrounded by a blue haze.

Single lenses are liable to two great classes of errors, the first only concerning us here.

Class (1) Axial.
,, (2) Oblique.

The effective aperture of the refracting system of the eye, that is, the area employed for producing the macular image, is so small that the oblique aberrations due to corrective lenses may be neglected, but it is quite different with a photographic objective of considerable aperture, whose purpose is to produce an image with good definition throughout its area. All the human eye requires is that the macular image shall have perfect definition, but the retinal area outside the macula may have quite a blurred one.

Axial aberrations are *chromatic and spherical*.

Experiment. Take a prism of about 10° refracting angle, view some such object as a horizontal window bar through it, and note that, besides appearing deflected and bent, its edges are tinged with a number of colours.

Owing to the fact that different coloured lights do not travel all at the same speed through transparent substances, such as glass or water, whenever refraction takes place there results a *dispersion* or breaking up of a composite beam of white light into its various coloured constituents. Even when light falls normally upon the separating surface the different coloured lights, that is the different wave motions in the ether, are retarded in varying degrees, and it is not difficult to conceive that light whose time period is short (green, blue, violet), should be retarded most, and consequently bent most, when refraction takes place, for this light has to vibrate so much more frequently.

Phenomena due to dispersion are many and varied. Let us examine a few. In the first place, instead of the simple refracted wave front shown in Fig. 18, when the incident light is white the refracted wave front must be represented by a fan shape, because the rates of propagation differ for the colours in the order V.I.B.G.Y.O.R. Red is retarded least, and violet most, and as the refractive index, n_2, of the glass is by definition $= \frac{V_0}{V_2}$ (since $n_0 = 1$), it follows that the refractive index varies with the colour of the light *for the same piece of glass*. In practice it is usual therefore to state the n for a particular position in the solar spectrum, that is for a particular coloured light, that chosen being yellow, and the line in the spectrum is known as the "D" line. This colour, with its characteristic line, may be produced artificially by burning sodium, and so producing luminous sodium vapour.

If these refracted waves proceed and finally emerge from another surface of the glass *parallel to the first*, they will do so parallel one with another. Therefore their various new paths will also be parallel, and the amount by which the waves are *deflected* from their original path also depends upon the colour of the light—in other words upon the refractive index, or change in velocity. Colours so produced by refraction will not be seen by the eye, because they will overlap one another almost instantaneously upon the retina, and therefore act as a composite wave of white light. If, however, one surface of the glass is tilted with respect to the other to form a prism, the light becomes separated out quite clearly, the incident beam being split up into the component beams upon emerging from the glass. The phenomenon witnessed in the experiment can now be explained. When the prism is held thin edge (apex) up the bar appears tinged with colours—the top edge red and the lower edge blue and violet, other colours will not be visible. We might, at first sight, expect that red would appear below and blue at the top, but in the case of the window bar we have really *two* beams, or portions of composite waves of light, one from the upper and one

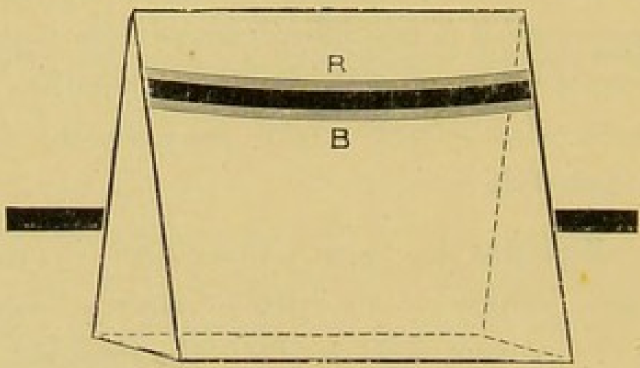


Fig. 29.

from the lower white pane, so that two spectra are formed, and where their ends overlap the dark bar there the particular colours will be visible. On looking through the prism the image of the bar is also bent, because the light reaching the eye from the ends of the bar has to pass obliquely through the prism, and therefore through a greater thickness of glass, hence the retardation will be greater, and consequently also the angle of deviation, i.e., the angle which the emergent path of the wave of light makes with the original path (angle δ in Fig. 17). The angle of deviation increasing gradually, as we look from the centre outwards the bar will appear curved, with its ends up when the prism is held apex up (Fig. 29), and vice versâ. Light passing obliquely through the prism acts just as if it were passed through a prism of greater refracting angle.

The effect of dispersion, and consequently the difference in the refractive indices for different coloured lights with the same piece of glass, gives rise to a phenomenon termed *chromatic aberration*. This is in practice termed a *defect*, because it produces a want of definition in the image. Let us consider the formation of an image by a convex lens. In Fig. 30 A B is a luminous object giving out waves of white light, differing in time period, or rate of vibration, for its constituent colours. All these different coloured waves, forming white light, travel with practically the same velocity in air, and so will meet the lens together, but they will not travel with equal velocities through the lens, violet waves being retarded most, and therefore have the greatest curvature. This being the case they come to a focus first, as the diagram shows. Moreover, the violet image, so formed, is smaller than the others, the red being the largest. The distance V R is termed the *chromatic difference*, and is a measure

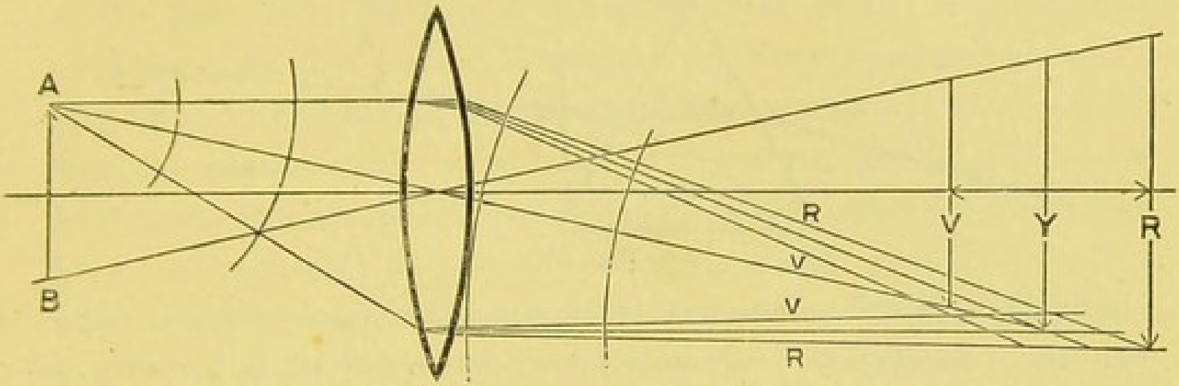


Fig. 30.

of the aberration or defect. In practice this defect is corrected by neutralizing the chromatic difference with another lens of opposite power, without destroying the deviating or focussing power. This can be accomplished by making the second lens from another kind of glass. For instance, if we take a glass list* we may find, among others, constant, such as the following :—

	n_D	$\Delta = (n_F - n_C)$	$N = \left(\frac{n_D - 1}{n_F - n_C}\right)$
Crown.	1·5175	·00856	60·5
Flint.	1·6214	·01722	36·1

These constants tell us that the flint glass retards the waves of light to a greater extent than the crown, and therefore that, other things being equal, greater refraction (and deviation) will occur when light passes through it. Furthermore, they tell us that between two given positions in the solar spectrum, the F and C lines, the *difference* in refractive index for the flint glass is about double that for the crown, and consequently but a comparatively small amount of deviating power is required in the flint glass to neutralize the dispersive effect of the crown. Thus a residual deviating (focussing) power will remain. A combination of two or more prisms or lenses, which in this way unite all the coloured waves again, is termed an *achromatic* system, the exact manner in which the waves are united in each case being seen in Fig. 31.

* For an explanation of the symbols see list at end of book.

Although the two spectra formed by the crown and flint prisms C and F respectively, at a given distance, may be equal in total length, it is more than probable that there will be irregularities in the spreading out of the

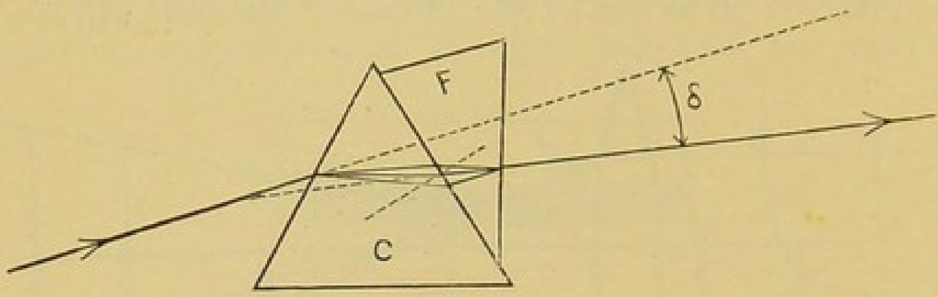


Fig. 31.

individual colours. This fact is known as the *irrationality of dispersion*. In all probability the various coloured waves will *not* be perfectly united, and when this is so what is known as a *secondary spectrum* is formed.

We find that a lens with surfaces ground truly spherical refracts light to a greater extent as it strikes the lens nearer its periphery, so that this part will have quite a different power from the central portion. We may satisfy ourselves that such is actually the case in the following manner:—Taking a rather large double convex lens let us imagine two paths of a plane incident wave, and assume that the path near the axis makes an angle of incidence of 5° at the first surface, and that the path near the periphery makes an angle of incidence of 25°. Call these angles i_1 and i_2 respectively. Then the ratio $\frac{i_2}{i_1} = 5$.

Now we have seen that $n_0 \sin i = n_2 \sin r$

Let $n_0 = 1$ and $n_2 = 1{\cdot}5$, then for Case I., we have—

$$\sin r_1 = \frac{\sin i_1}{n_2}$$

$$= \frac{{\cdot}0871557}{1{\cdot}5} = {\cdot}058104$$

$$\therefore \; r_1 = 3^\circ \; 20'$$

And for Case II.—

$$\sin r_2 = \frac{\sin i_2}{n_2}$$

$$= \frac{{\cdot}4226183}{1{\cdot}5} = {\cdot}281745$$

$$\therefore \; r_2 = 16^\circ \; 22'.$$

Therefore the ratio $\frac{r_2}{r_1} \doteq 4{\cdot}91$. But the ratio $\frac{i_2}{i_1} = 5$. Therefore the path near the periphery of the lens must be bent proportionately more, and consequently cut the axis at a point *nearer* to the refracting surface than the point to which the central path is bent. It is clear, too, that refraction at the second surface of the lens will increase this effect, or error of spherical aberration, as it is termed. Moreover, if the angle of emergence of the light from the second surface is equal to the original angle of incidence at the first surface, a condition known as symmetrical refraction, then the error of spherical aberration will be at a minimum for the particular lens and aperture under consideration. For this reason a plano-convex lens should have its convex surface faced towards parallel incident light, a feature noticeable in the objectives of opera glasses and telescopes. It is rarely a matter of any difficulty to reduce this aberration to a minimum, but it is one of considerable trouble to satisfy the condition for its elimination. The distance between the axial focus and the peripheral focus for the given aperture and lens may be termed the *aplanatic difference*, and is a measure of the aberration or defect. A combination of lenses which satisfies the condition for the elimination of spherical aberration is termed an *aplanatic* system, and if a lens system is corrected both for chromatic and spherical aberration the whole combination may be termed a *collinear lens*, and the emergent waves of light will be perfect spherical ones.

The defect of chromatic aberration is quite marked in the human eye, and we need only look out of the corner of the eye at a window bar against a white background to prove the defect. Since, however, we depend almost entirely upon direct or axial vision the presence of this error causes us no inconvenience. The human eye possesses the defect of spherical aberration, but not to any great extent, owing to the peculiar formation of its crystalline lens, whose refractive index gradually increases from the periphery inwards, thereby counteracting the effect of the gradual excess over the necessary refracting power from the centre outwards due to the sphericity of its surfaces. (See Chapter IX.)

Summary :—

(*a*) Axial aberrations are chromatic and spherical.

(*b*) n varies with the colour of the light for the same refractive medium.

(*c*) The order of colours in ordinary dispersion is expressed by the coined word VIBGYOR.

(*d*) The refraction of spherical lenses is greater as the incident path of light moves from the axis to the periphery.

Section II.

Physiological Optics.

CHAPTER VII.

THE PHYSIOLOGICAL STRUCTURE OF THE EYE.

FOR the purpose of understanding the function of the eye it is necessary that its structure should be described, but limits of space will only allow such matters to be dealt with as have a distinct bearing on refraction.

The eye is the product of an outgrowth of the brain and a part of the integument of the body, its development commencing at a very early stage of fœtal life, the optic nerve and retina, with its attendant pigment layer, being formed from a hollow offshoot of the rudimentary brain, which is pushed out to meet and encircle a horny closed pit formed in the external integument or skin.

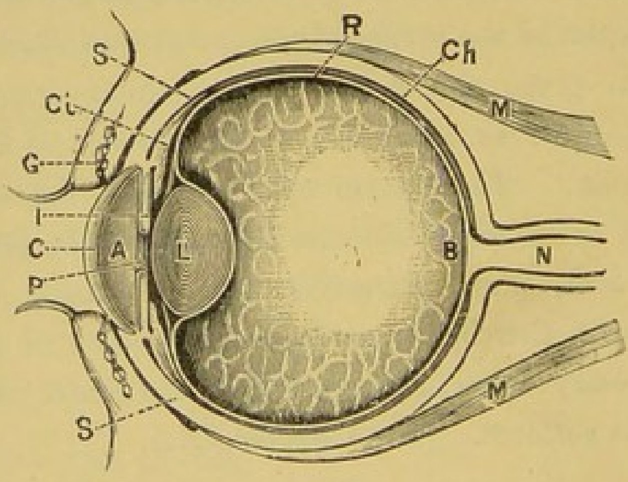


Fig. 32.

Longitudinal section of the eye from above downwards:— S, Sclerotic coat. C, Cornea. L, Crystalline lens. A, Anterior chamber. N, Optic nerve. B, Optic pore or disc. Ch., Choroid coat. R, Retina. P, Pupil. I, Iris. Ci., Ciliary Muscle. G, Glands. M, Superior and Inferior recti muscles.

The other parts, the vitreous, choroid, iris and sclerotic are formed from what is called the middle germinal layer.

This method of development is worthy of notice, because it shows clearly the intimate connexion between the retina and the brain; in fact some authorities consider the optic nerve as really a part of the brain, and it is clear that the retina is merely an elaborated expansion of that nervous channel. The lens is purely a device for focussing the incoming waves of light so that a distinct image may be obtained, and the choroid, with its attendant iris, forms the background and light regulating arrangement.

The protective system, which also does duty in preservation of form under strain and rotary movement, consists of a hard, shining, tough membrane, the sclerotic, which becomes transparent in front to form the *cornea*, a more highly differentiated structure of about 1 mm. thickness, which is let into the circular aperture of the sclerotic in a similar way to what a watch glass is inserted into its bezel, except that the fibres of the cornea become continuous with those of the sclerotic. The cornea is protected upon the outside by several layers of cells known as the anterior epithelium, underneath which is the substance proper, an outer thin part, often called Bowman's membrane, being particularly compact (Fig. 33). Inside the main substance is a thin layer of about ·01 mm. thickness, of great elasticity, called Descemet's membrane, and having a tendency to roll up when broken through. Inside this, and adjoining the aqueous humour, is a single layer of epithelial cells.

The corneal surface is not a part of any regular figure, for it has normally a greater curvature vertically than horizontally, and has a central area differing in curvature from the periphery.

The central portion has a diameter of about 4 mm., and is practically the segment of a sphere of about 7·8 mm. radius; it is called the *optic* part, and corresponds fairly well with the average size of the pupil behind it, while the surrounding periphery is known as the *basilar* part, this diminishing in curvature rapidly near the optic part, and falling still further to the margin. There is also a variation between the curvatures of the temporal and nasal sides, the latter being more flattened, and this sometimes can be detected, even in the optic part, by means of Young's optometer.

The cornea has a refracting power for its anterior surface of about + 47 D, and for its posterior surface (whose radius of curvature is about 6 mm) of nearly — 5 D, so that the total value is about + 42 D, which is over $2\frac{1}{2}$ times as great as that of the crystalline lens.

The *aqueous humour* is a watery fluid, scarcely distinguishable from that liquid, with an index of refraction of 1·337. Its limpidity allows for the movement of the crystalline during accommodation, and also for the changes in the iris. It is quickly replaced after puncture of the cornea by accident or operation, its total volume lying in a crescentic space of about 13 mm. diameter and 3 mm. deep, forming the large anterior chamber in front of the iris, with a small, so-called posterior chamber between the roots of the iris and the lens.

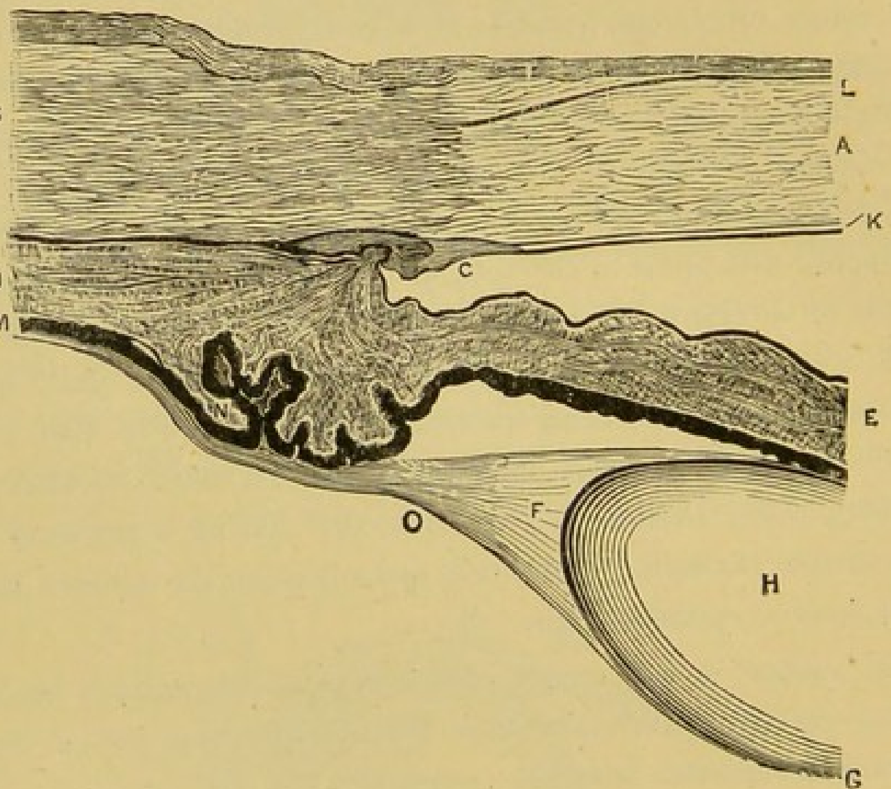


Fig. 33.

This illustration is partly from an actual section and partly diagrammatic. A, Cornea. B, Sclerotic. C, Ligamentum pectinatum, with Schlemm's canal. D, Ciliary muscle. E, Iris. G and F, Zonule of Zinn, or Suspensory ligament, F being the region of the Canal of Petit. G, Lens capsule. H, Crystalline lens. K, Descemet's membrane. L, Bowman's membrane. M, Pigment layer. N, A ciliary process.

The *vitreous humour* occupies the posterior ⅘th of the eyeball. It is a jelly-like substance resembling the albumen of an egg, and gives the impression of being divided by fine clefts. It has the same index of refraction as the aqueous humour, and is attached to the retinal margin all round, the existence of a containing membrane, except in early life, being disputed. It serves as a support for the retina, which is spread over its surface, and lessening of its substance is apt to cause detachment of that membrane from the wall of the globe. Both this and the aqueous are secreted by the uveal tract, a region comprising the ciliary body and its appendages.

Between the two humours lies the crystalline lens, within a capsule attached to prominent processes from the uveal tract by the suspensory ligament, which adheres to those on the posterior side, and is also attached to some of the anterior ones. (Fig. 33).

The capsule of the lens is smooth and inextensible, with an inner lining of cells in a single layer upon its anterior surface only. It is attached to irregular masses of deeply pigmented projections, known as the *ciliary processes*, by a peculiar system of cords cemented together and arranged in a radiating fringe which extends all round. These are called collectively the *suspensory ligament* or *zonule of Zinn*, and are attached over a considerable portion of the edges of the capsule, merging into its substance, many of them crossing from the back of the processes to the front of the capsule. Inside these, around the periphery of the lens is a space called the *canal of Petit.*

The *crystalline lens* is a firm transparent body, with a much greater convexity on its posterior than its anterior surface, and is composed of a series of lamellae, or plates of fibres, which can be peeled off like the coats of an onion, when the lens has been hardened in spirit or boiling water. The central portion of the lens has a greater consistency and is more spherical in form ; it is known as the *nucleus*, and has, except in infancy, a higher index of refraction than its surrounding layers, or *cortex*, in fact there seems to be a gradual reduction in value for n from the centre outwards, an arrangement which lessens spherical aberration.

A further peculiarity is the arrangement of fibres, which are bent round at the margins of the lens, giving the impression of being under tension when the surfaces of the lens are compressed. Under certain conditions, as by use of the pinhole disc with a bright cloud as background, sutures of the lens are subjectively visible. These meet in the centre and radiate outwards, varying in number according to age, in youth generally being seen as three, those corresponding on the opposite surface appearing between them, so that double the number upon each surface is visible.

The fact of the crystalline lens having a hard centre and softer cortex has played a great part in the controversy over the mechanism of accommodation, because any pull or traction upon the zonule would cause the surfaces, and especially the anterior one, to form a *lenticonus*, a shape similar to what was described as that of the cornea, a central more highly curved portion, with flatter sloping margins.

Closely connected with the lens is a series of structures known as the *ciliary body* and the *iris*, with a pigmented continuation which envelops $\frac{4}{5}$ths of the eye as a coat called the *choroid*, this forming a sort of background to the retina, and being, in the part near the structures we are considering, moveable over the sclerotic with a gliding motion.

Near the sclero-corneal union there is a scallop shaped mass of fibrous cords, the *ciliary ligament*, or *ligamentum pectinatum iridis*, inclosing a number of open spaces called the *canals of Fontana*, which communicate with the aqueous and also with the *canal of Schlemm*, a vessel running around the eye under the sclero-corneal junction. The sclerotic is strengthened about this part, and to the ligament the triangular shaped *ciliary muscle* is attached, with the longest side against the sclerotic. A peculiar feature of this muscle, composed as it is of unstriped fibres, is that the fibres may be roughly divided into three groups, the one longitudinal, running from front to back, the second transverse, and the third circular, passing in a circumferential direction round the position of the lens. They all merge from one form to the other gradually, the groups not being sharply defined.

The individual fibres are quite different from those of the external muscles, being spindle shaped and shorter, fitting side by side, with the thinner part of one against the thicker parts of two others. They contract slowly, and are not usually under the control of the will, being called involuntary or organic, the latter name including them with muscles found in the various organs, such as the stomach, in contradistinction from those of the motor muscles of the limbs, to which class the external muscles of the eye belong.

Surrounding the ciliary muscle is the substance proper of the ciliary body, raised into a number of prominences called the ciliary processes, and falling away anteriorly until it becomes the iris, while posteriorly it flattens out into the choroid coat. The whole arrangement is covered by a layer of dense pigment, and, from the conformation of parts, this covers the posterior side of the *iris*, a thin disc floating in the aqueous, with an aperture, practically circular in form, called the *pupil*. The iris varies in thickness from about $\frac{1}{2}$ mm. at the aperture to $\frac{1}{4}$ mm. at its attachment, and is provided both with a circular muscle, the *sphincter pupillae*, which constricts the pupil, and a series of fine radiating fibres, forming the *dilator pupillae* muscle, by which the aperture is enlarged.

The *choroid coat* underlies the retina, and between it and that membrane is a thin pigment layer which belongs to the retina itself, although in dissection it appears to be united to the black and heavy choroid, in reality being separated from it by the glass like fine transparent *membrane of Bruch* or *lamina vitrea* (Fig. 34). The choroid is a highly vascular membrane, having abundant blood vessels, its colouring matter varying from light brown in fair complexioned people, to black in darker races and negroes.

The retina is a most delicate membrane of very complex structure, and unless care is exercised in removing the vitreous humour when dissecting an eye, it seems to float over the choroid and gather in fine folds around the entrance to the optic nerve, although it covers the whole of the back of the eye, ending in a wavy border, the *ora serrata*, where the choroid proper also ceases. This position is coincident with the starting point of the ciliary body, and the retina is continued over that, as a single layer of cells, up to the root of the iris, being known over this region as the *pars ciliaris retinae* or ciliary part of the retina.

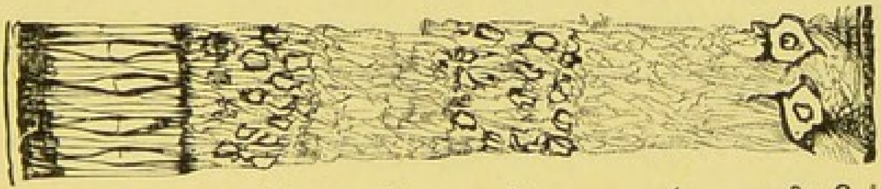


Fig. 34.

1. Internal limiting membrane. 2. Nerve fibres. 3. Nerve cells. 4. Internal molecular layer. 5. Internal nuclear layer. 6. External molecular layer. 7. External nuclear layer. 8. External limiting membrane. 9. Rods and cones. 10. Pigmented epithelium. 11. Lamina vitrea.

At the *fovea centralis* (central pit) of the *macula lutea* (yellow spot of Soemmering), the minute area of most distinct vision, the retina has a thickness of little more than ·1 mm., but elsewhere it averages about ·25 mm. The yellow spot is immediately opposite the pupil, and only about 3 mm. from the *punctum caecum* or blind spot of Mariotte, which because of being the entrance of the optic nerve is known variously as the *optic disc*, *papilla*, or *pore*, and is about 1·5 to 2 mm. across. The blood vessels supplying the retina enter at the papilla and branch out, the larger ones seeming to avoid the macula, although it is well supplied with capillaries.

The above figure represents a diagrammatic section of the retina, from which it will be seen that 10 layers are represented, the number of these being different with various authorities. The whole structure may best be considered as a framework of fibres, the *fibres of Müller*, running from front to back, between the *membrana limitans externa* and the *membrana limitans interna*, the other structures being supported by them.

The layers shown, except the receptive one of rods and cones, are merely various forms of nerve fibres with roundish or ovoid nerve cells in the nuclear layers. The ganglionic layer consists of much larger nerve cells, each possessing several arms or processes and a distinct large nucleus, the bodies being apparently connected up by the processes with the layer of nerves immediately adjoining, the strands of which are ramifications of the optic nerve.

The retina is thus an expansion of the optic nerve, with its receptive portion away from the incident light, which has to travel through the entire thickness of the membrane to reach the rods and cones.

Summary :—

(*a*) The eye is formed by an outgrowth from the brain uniting with a development of part of the integument.

(*b*) The cornea has a central optic part and a flatter surrounding basilar portion.

(*c*) The lens capsule is a membrane, but the suspensory ligament is merely a series of cords fitting closely together.

(*d*) The crystalline lens develops a harder central nucleus with growth.

(*e*) The ciliary muscle has three principal arrangements of its fibres.

(*f*) The retina is a membraneous expansion of the optic nerve.

CHAPTER VIII.

HOW WE DISCERN OBJECTS.

THE eye is especially adapted for forming on the retina images of external objects, which are real, inverted, and diminished. But a little consideration shows us that vision is not complete at this stage, for if the optic nerve, which connects the retina with the brain, be diseased or severed, or the brain non-receptive, we do not see external objects, although the images may be sharply formed upon the retina. Nor does the sleeper, with eyes wide open, possess vision, for stimuli may actually be transmitted to the brain (evidenced in somnambulism), but the visual centres there are not all in activity. It is therefore clear that some structures outside the eyeball are concerned in the ultimate interpretation of these retinal images. Beyond locating them in the brain we cannot here pursue the enquiry. There seems to be little doubt but that the rods and cones of the retina convert the etheric vibrations into actual nerve stimuli. A direct connection can be traced between each rod and cone to its particular optic ganglion, and although every such connection has perhaps two distinct breaks in it there are reasons for assigning them a purpose. That both rods and cones are light sensitive we know, for they are distributed over the retina in a very peculiar, although regular, manner.

Where the visual axis cuts the retina, only cones, which are of a minimum size, are found, and just at this central part of the retina (the fovea centralis) they are packed much closer together than elsewhere. Over the whole of the macula lutea the cones are but one-third of their usual size and more numerous, whereas the other elements—the rods—are almost entirely absent. The number is certainly so small as to make their presence useless. As we pass away from the fovea centralis in all directions we find that up to the periphery of the region of the macula, the cones, which alone are present in this region, gradually get larger and larger and less numerous. At the periphery of the region of the macula is the peculiar formation of one or two isolated cones surrounded by a number of rods, and this extends right round the part referred to. Proceeding still further, we find a region containing a very even and regular distribution of rods and cones; this is the main portion of the layer of rods and cones, and extends from the periphery of the yellow spot region nearly, but not quite, to the limit of the retina. At the actual edge rods only exist, and these, with a few quite close to the region of the yellow spot, are colourless. All the others, under the action of light, draw upon the pigmented epithelium layer of the retina for pigment, and so receive their colour. The function of the epithelium layer seems to be to supply visual purple to the rods as fast as the pigment already in them is bleached by light, and experiment seems to suggest that sometimes they become "saturated," that is, all the pigment at their disposal becomes bleached, after which they no longer respond to *light* vibrations.

From the foregoing it will be noticed that direct vision is cone vision, this embracing an angular field of view of about 6°. We are therefore in a position to determine experimentally the capabilities and limits of cone (or central) vision.

We may draw up the following particulars respecting the functions of the rods and cones in producing *vision*, and it is worth while noticing how each group of end-organs has its particular sphere of activity. The cones give us perfect direct vision, and very good oblique vision in good light—during the daytime, for instance; while the rods enable us to judge the general outline of objects by indirect (oblique) vision when the light is feeble, as at twilight.

It is probable that:—

1.—The rods are capable of producing the sensation of light.

2.—They have a normal form acuity of the order of 6/60 (Snellen's Types).

3.—They are unable to respond in such a manner as to produce the sensation of colour.

4.—They only respond to any extent when the illumination is of the order of between $\frac{1}{100}$th and $\frac{1}{4}$ candle-meter.

5.—They are most easily excited by the more refrangible rays of the green and blue. Since they are colour-blind, however, the visual spectrum at a sufficiently low illumination (when the *cones* are not acting) appears *grey* throughout, is contracted towards the red end a little and appears brightest in the region of the green.

6.—As there are no rods within the yellow spot, at low illuminations, when the cones are not acting, this will appear as a black spot in the field of view, and may be easily seen. In rather dark twilight, looking steadily at the heavens with one eye, this black spot appears in the centre of the field of view, and looks smaller than it should do, owing to the difficulty of keeping the eye steady, and to the fact that rods are very numerous just at the periphery of the region of the yellow spot. When observing phenomena at these low illuminations it is interesting to note that we often think we are looking directly at an object, when as a matter of fact the line of vision is tilted three or four degrees with respect to the true visual axis passing through the fovea centralis.

It is probable that :—

1.—The cones are capable of producing the sensation of light.

2.—They have a normal form of acuity of 6/3 to 6/6 (Snellen's Types).

3.—They are capable of producing the sensation of colour, *i.e.*, they are capable in some way of responding differently to light of varying wave-lengths.

4.—They do not respond if the illumination falls below the order of $\frac{1}{4}$ candle-meter.

5.—They are most easily excited by light in the yellow region of the spectrum.

6.—They are capable of detecting a change of approximately 1 per cent, in the intensity of illumination (Weber-Fechner Law). This law does not hold for very low or very high intensities of illumination. but our ordinary sensations of light and shade (form sense) follow from it.

The above explains why different writers give different values for the maximum of the luminosity curve, all of which can be grouped under two headings. The values given for the position of the maximum are either $\lambda = \cdot 53\ \mu$ or $\lambda = \cdot 58\ \mu$, showing very clearly that they refer either to rod vision or cone vision. For rod vision the maximum corresponds with $\lambda = \cdot 53\mu$ (green) and with cone vision the maximum corresponds with $\lambda = \cdot 58\mu$ (yellow). These values are approximate only.

Experiment tends to show that these end-organs of vision rarely act simultaneously. Sometimes both may be acting, but in such instances the action of one of the sets is not at a maximum.

It was for a long time a very vexed question as to how the retinal images, although inverted, were interpreted as erect. Buffon attributed it to reason, while another observer, Lamé, made the consciousness of movement of the eyes the ruling factor; we look at the top of an object and the eyes are raised; to view the lower portions they are depressed. There is a certain amount of truth in Lamé's deductions, but observations on persons born blind, who have, through operation, received sight, show that these see things erect at once, and have such a correct appreciation of external objects as we should scarcely expect if either theory were a sufficient explanation. The real interpretation seems a simple one. We see everything *outside* the eye, it is merely the picture of things which is situated *inside* the eye, and as light comes from points in the outer world we refer them to the direction of origin, locating them in the direction whence they started. To such an extent is this true, that when any point actually inside the eye is made visible we refer it to the outer world.

This can readily be proved by looking at the empty field of a microscope, when, after a time, minute particles, or strings of beads appears. These are images of bodies floating in the vitreous humour, but they appear as if they were in the field of the microscope. Consequently, it is evident that our sensations tell us nothing of the image on the retina; if it is defective we only have the sensation that the object looked at appears defective. Nor should we ever know, except by actual observation of its formation in another eye, that the retinal image was itself an inverted one. That we have no sensation of the state of the retinal image is further evidenced by the experiment of cross and dot.

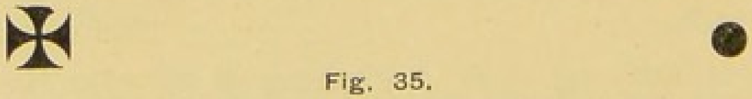


Fig. 35.

By closing one eye, and looking at the cross with the other at a distance of about 10 inches, a position is found where the dot disappears, because its image falls upon the blind-spot of the retina. There is a break in the retinal image at the entrance of the optic nerve, but there is no break in the field of vision as we see it by one eye used alone; experiment only shows this. If we saw the outside world in exactly the state in which it appears on the retina, we should be conscious of this blank in the field of vision, for we can readily imagine that one half of the image of a large object might fall on the blind-spot, and the other half on a perceptive area adjoining.

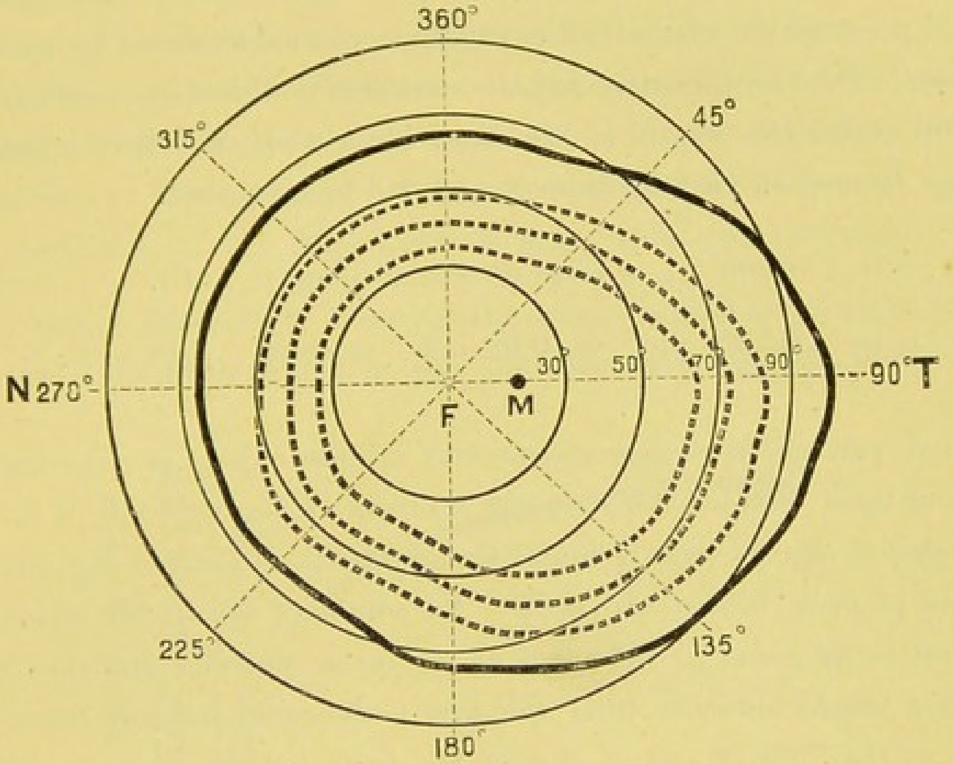


Fig. 36.

F represents the fixation point, and M the blind-spot of Mariotte. The dark line encloses the field of vision for white, the dotted ones representing those for BLUE, RED and GREEN in order, from out inwards.

The *total field of vision*, the *central field of vision*, and the *area of most distinct vision*, should be carefully distinguished one from another. The area of the total field which is light perceptive is by no means the same for all colours. In Fig. 36, the normal field for the right eye is diagramatically shown. It is worthy of notice that no special spectral order is maintained, and no satisfactory explanation has been given of this peculiarity.

The small central area F (about 2 mm.) in the diagram represents the central field of vision. Over the whole of this area definition of a high order is maintained for the retinal image, but the area of most distinct vision is merely a point in the middle of this central field, with a diameter of about 0·25 to 0·3 mm. (about $\frac{1}{80}$th inch). This point area is the fovea centralis, and in subjective sight-testing it is to the minute point area we direct our attention, using the standard letters of Snellen's type at a distance of 6 metres. The size of the retinal image is easily calculated when we know that of the object, for the relation depends upon the distance of each from the nodal point of the eye. Snellen's letters, No. 6, are 8·5 mm. in length and breadth and they should be for normal vision, at a distance of 6 metres from the first nodal point of the eye, which is usually reckoned as about 15 mm. from the retina. Therefore we may put the question in this form :—If at 6 metres (6000 mm.) the object is 8·5 mm. long, what will be the length of the image formed at 15 mm. from the second nodal point ?

Obviously, $8·5 : 6000 :: x$ (size of retinal image) $: 15$.

Therefore $x = \frac{8·5 \times 15}{6000}$ mm. $= 0·02$ mm., or about $\frac{1}{1250}$th inch.

The retinal perception of any except very minute objects is remarkable. The area of most distinct vision (fovea centralis) being so small, it follows that the size of objects strictly limits the capability of getting the image of the whole of each within the area. An angle of 60 to 90 minutes at the second nodal point is subtended by the fovea centralis, and consequently a similar angle outward from the first nodal point through the cornea will give us the limit of size of objects for very distinct vision. About three times the apparent diameter of the moon, when at some distance from the horizon, is the full size. Even then we can readily observe that we discriminate between different parts of this space. In other words, we can fix a point, while retaining all other parts immediately around in the best position for accurate vision, the point fixed being the centre of this area. The line passing from this *fixation point* to the first nodal point is called the *visual line*, and after refraction this line passes on to the fovea as if it came from the second nodal point.

When looking at any object there are four attributes of that object which we note in viewing it. Experience is so varied, and so frequent, that we do not think of these, unless for some cause our attention is specially directed to them. They are light, form, colour, and size. Light and colour are purely retinal perceptions. The others, although a direct consequence of our light perception, require a certain amount of muscular action to guide us in judging them. It has been mentioned that within ordinary limits we can discriminate between the brightness of two objects (similar colours) when the one is brighter than the other by 100th part of the total. At the present time it is assumed to be sufficient to test simply the "form" acuity. Acuity for light and colour is—except in very rare instances—entirely neglected, because we assume that no treatment can improve either. Whether this is so or not, the importance of knowing something about a client's colour and light acuity is evident, because a subnormal light acuity almost invariably points to grave disease, when not a consequence of colour-blindness. Again, the highest form acuity under ordinary conditions is almost impossible with the colour or light acuity subnormal to any extent. When we speak of *visual acuity* we refer to the conditions of the sensations of light, form, and colour.

The form acuity depends to some extent upon the amount of light received by the eye, a point illustrated by the curve shown in Fig 37, which represents

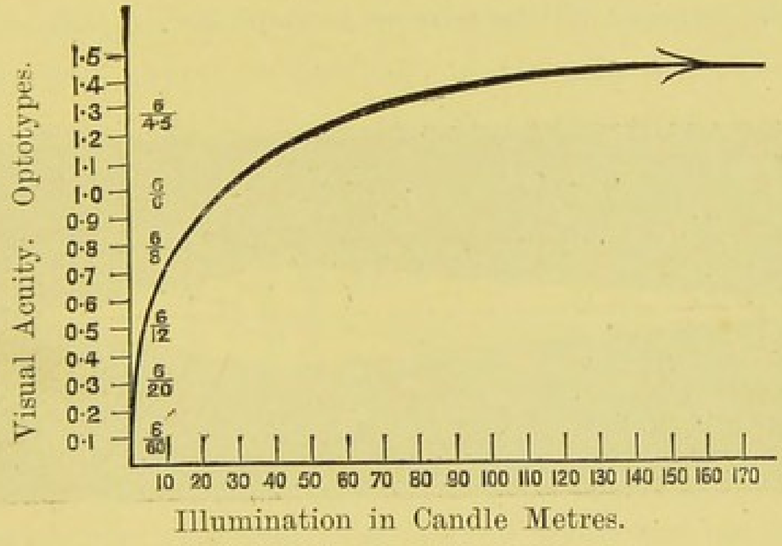


Fig. 37.

the state of the form acuity in the normal emmetropic eye for various degrees of illumination. The curve is interesting for the reason that it indicates the advisability of illuminating the test-types for subjective sight-testing to the extent of at least 30 candle-metres. One candle-metre is the illumination received at one metre distance by a screen directly facing a luminous source of *one candle power*. The brilliancy of the retinal image, and, therefore, the apparent brightness of an object, is quite independent of the size of the object and its distance from the eye. For if the object increases in size the retinal image does too by a corresponding amount ; and if the distance of the object from the eye is altered the reduction or increase in the size of the retinal image is just such as to maintain its brilliancy at its original value. The stimulations set up, therefore, by every end-organ of vision will be the same. It is true that the number employed is different in the various cases quoted, but it is the state of the individual end-organs which determines the amount of light sensation produced.

For perfect form acuity, besides being able to detect small differences in light and shade, it is essential that the boundary lines between the objects of varying luminous intensities should be clearly defined upon the retina itself. This is accomplished by a lens system which is by no means theoretically perfect, but since very good definition is only required when the illumination is considerable, and the retinal image small, its perfection is ample in practice. There are, however, instances in which the non-achromatism of the eye influences the phenomena witnessed, and one or two such instances will be referred to hereafter.

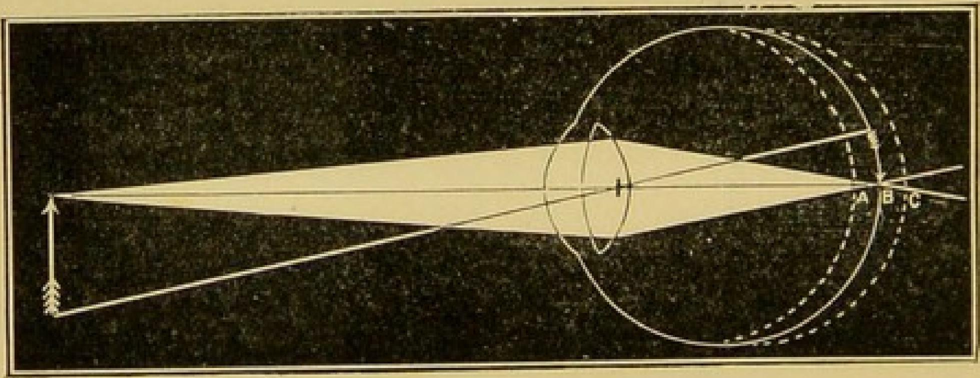


Fig. 38.

The great optical essential of distinct vision is that the object seen and the image on the retina shall be conjugate foci. This is shown in Fig. 38, where the object is the point of an arrow. In any other position of the retina but that of the middle line in the diagram, the waves do not come to a point upon it. If we imagine the retina either nearer the cornea or further back, as shown by the dotted lines, it is evident that in the one case the light is still convergent, and in the other it is divergent, having passed the focus. It is also clear that instead of a collection of focal points we shall have circles, the same quantity of light being spread over an area depending upon the position of the retina, with an illumination lessening over the whole space as the area becomes larger. These circles are known as *diffusion circles*. They are circular because the pupil is a round aperture. If the pupil were a long oval, as in some animals' eyes, the diffusion spots would be oval in front of or behind the focus, although at the screen, where the image is perfect, this would have no effect. *A straight line viewed by a myopic eye (the long form depicted) gives an image which is composed of an infinite number of diffusion circles, all of the same size, closely overlapping each other, so that the line looks blurred.* This indistinct image will stimulate a greater number of cones (ordinary illumination) at the fovea, but although the total stimulation will be as great, each cone will be stimulated to a less degree, so that the object will appear less bright. The difference between the *point* image and the *diffuse* image of any external point is the foundation of the difference between the images of emmetropic and most forms of ametropic eyes.

Intimately connected with the form acuity are the limits placed upon the visual resolving power, or capability of detecting as two, two distinct and separate objects. *First*, there is the physiological limit at ordinary illuminations, and for each portion of the retina this may be expressed in angular measure by that angle subtended by two adjacent cones, in this region, at the second nodal point of the eye. *Secondly*, there is the physiological limit at very low illuminations, which may be expressed in angular measure by that angle subtended by two adjacent rods at the second nodal point. *Thirdly*, there is the *natural* limit placed upon one's resolving power owing to the finite size of the wave-length of light. It is because the wave-length of light is finite that the image of a *point* object is never a single point, but a point surrounded by alternate dark and light rings.

If, therefore, we think of the retinal images of two distant point sources of light, we must realise that each of these images is a disc surrounded by bright rings separated by circles at which the intensity vanishes. Each image is what is termed a *diffraction* image, and it will be noticed that when the first dark ring of one image overlaps the central bright disc (point) of the other, we shall be unable to distinguish the two point objects as two.

A measure of this natural limit is given by that angle subtended by the two central point images at the second nodal point of the eye when the first dark ring of the one image overlaps the central bright disc of the other. This natural limit does sometimes exceed the physiological limit at ordinary illuminations. The physiological limit for cone vision for the area of most distinct vision is placed at 1 minute (Snellen's types are based on this assumption), but as a matter of fact this is a *high* value for the minimum angle at the fovea centralis, 50 seconds being probably a nearer average.

Summary :—

(*a*) Upon the retina is formed a real, inverted, and diminished image which the brain interprets.

(*b*) The area of most distinct vision is confined to the fovea centralis of the yellow spot.

(*c*) The cones are colour sensitive, the rods probably not so, but become especially active in low illuminations.

(*d*) An illumination of at least 30 candle-metres is advisable in testing.

Chapter IX.

IMPERFECTIONS: PHYSIOLOGICAL AND OPTICAL.

THE emmetropic or normal eye possesses nearly every defect which could possibly have been crowded into an optical system. This is especially true if we are allowed to take a number of eyes and enumerate the defects to be found in all of them. But we do not find all these in every eye, and where they do exist we may generally insert the saving clause to the above statement, that the degree of the defect is rarely so great as to be detrimental to ordinary vision, and not infrequently one defect counter-balances another.

To get a fairly complete scheme it will be observed that in the following arrangement ametropic eyes are included under anomalies in the shape of the eyeball, and, where ametropia is due to astigmatism, under anomalies of curvature. We may then tabulate them as follows :—

I. Physiological Imperfections.

(*a*) Anomalies in the shape of the eyeball.
(*b*) Anomalies in the curvature of the cornea.

II. Optical Imperfections.

(*a*) Incorrect centering.
(*b*) Spherical aberration.
(*c*) Chromatic aberration.
(*d*) Internal Reflection.
(*e*) Anomalies of the media.

This list is not exhaustive, and is devised chiefly in consideration of the effects of refraction.

Anomalies in the shape of the eyeball claim our first attention, as the majority of refractive errors are due to this cause. The eye may be either too short or too long: in the one case causing hyperopia and in the other myopia.

It is generally supposed that a difference of 1 mm. in length is equivalent to 2·5 D to 3·0 D of power, the eyeball being measured along the optic axis. The eye hyperopic through form may be regarded as imperfect or under-developed, frequently showing smaller dimensions in other directions, and in a state of rest light which is parallel before reaching the eye does not come to a focus soon enough, and consequently would focus at the back of the retina (Fig. 38). The eye myopic through form may be looked upon as one in which development has advanced beyond the normal, sometimes from certain weaknesses of tissue. In this case parallel light comes to a focus too soon.

Anomalies of curvature appertain to the cornea, and may take regular or irregular forms, when the effects are known as regular and irregular astigmatism respectively. The surface of the cornea is not that of a perfect sphere. (Chap. VII.)

Over the optic part the reflected image of a white square held in front of the cornea is perfect, but immediately off this area it suddenly elongates, owing to the flattening. Light passing through the basilar portion will not be refracted to the same extent as that passing through the optic part, and must often be excluded in order that a perfect image may be formed upon the retina. The normal pupil only allows the useful light to pass, but the dilated one, such as can be produced by atropine, allows all light to pass, useful and injurious alike, frequently causing some variation from the normal retinal image. The pupillary aperture, then, has a distinct use as a diaphragm in the formation of a perfect image, quite apart from the fact that it regulates, as a photostat, the quantity of light falling upon the retina. It is possible that the flattening of the cornea towards its periphery assists in reducing the amount of spherical aberration in certain instances.

In the normal (emmetropic) eye there is a constant relation between the radius of the cornea and the length of the eyeball. But this ideal form of cornea is rarely found. The average cornea, over the whole of its surface, is slightly longer from side to side than from above below, giving a greater curvature in the direction N S, as shown in Fig. 39. The optic part and the surrounding flatter region both share in this *normal astigmatism of the cornea.*

In some cases the cornea has an acquired peculiar cone-shaped projection, due to a weakening and stretching of the tissue, causing keratoconus, or conical cornea. The normal astigmatism of the cornea may be excessively

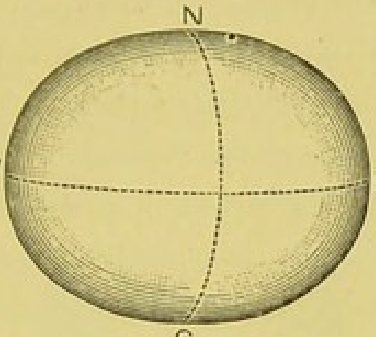


Fig. 39.

developed, producing myopic astigmatism, which requires a concave curvature in one meridian to correct it, or the opposite meridian (W E of Fig 39) may be deficient and require an added convex curvature, so placed as to raise its power. This is the characteristic of hyperopic astigmatism. The cornea, moreover, may have either kind of astigmatism developed in any other meridian, when it is known as *oblique*. If the vertical meridian differs in curvature from the horizontal, being in excess while the horizontal is deficient, we have a case of *mixed astigmatism "with the rule,"* the eye being both myopic and hypermetropic according to the meridian.

All these varieties are described as regular, in which there are always two principal meridians, one of highest and one of lowest curvature, generally at right angles to each other. Every meridian between these has a different curvature, increasing as it is nearer the maximum, and decreasing towards the minimum. The existence of lenticular anomalies of curvature is disputed: we have no adequate means of proving their existence in the living eye, but their presence has been suspected, owing to the occurrence of cases where we find either an additional astigmatism over and above the corneal amount, or a lessening of the corneal astigmatism, due to some internal anomaly. An explanation of these variations, so far as the lens is concerned, is probably found in the fact that sometimes it is slightly tilted from its normal position at right angles to the optic axis, just as a spherical lens so placed will show an astigmatism, one part receiving light from an object before another, thus giving rise to *astigmatism by incidence of the light.*

The optical imperfections are very numerous, and are of the same nature as those defects which it is the object of every manufacturer of photographic lenses to eliminate. The first which calls for remark is the incorrect centering of the lens or pupil, due to physiological causes. Where such errors exist the optic or polar axis does not pass through the optical or geometrical centres of one or both of them. The most usual defect of this nature is for the optic axis of the crystalline lens to be a trifle higher than the centre of the corneal curvature, but the lens may be eccentric in other directions. The pupil, too, frequently varies from its normal position, being displaced a little inwards, but occasionally it is so eccentric that the visual line does not pass through it, necessitating the operation for an artificial pupil (Chapter XV.). A physiological defect, which gives rise to a serious optical condition, is coloboma of the iris, a downward slit or space where the iris has failed to close during development. The pupils seems then to have a prolongation downwards, giving a curious cat-like appearance to eyes so affected. Naturally, marginal light is allowed to pass through the basilar portion of the lens, opposite where the opening occurs, causing blurring of vision.

Spherical aberration, explained in Chapter VI., is a defect common to most lenses, and to all single lenses with spherical surfaces.

To study the spherical aberration of the eye we must take the whole refracting system into account, as we cannot sufficiently separate that due to the cornea from that due to the lens. It may be positive or negative. Making the eye myopic by the use of a + 3 D or + 4 D lens we see a distant luminous point as a circle of diffusion, and by placing a fine needle behind this lens a shadow is cast upon the retina. If this shadow is straight in all positions the eye is *aplanatic*, or practically free from spherical aberration ; if the line is convex towards the centre we have the usual positive type of aberration, but if concave towards the centre it is negative, the axial portion focussing sooner than the margin, as in conical cornea. The contraction of the pupil has a considerable influence upon cutting off the marginal light which would blur vision, owing to the presence of aberration, especially for near objects.

The peculiar structure of the crystalline lens (Chap. VII.), considerably reduces the spherical aberration of the eye for parallel incident light, the lessening values of the index of refraction as we approach the margin reducing the refraction of the outer layers. The difference between the cortex and nucleus in this respect is sufficient in adult eyes to allow faint images to be reflected from the surface of the latter, by suitable arrangements.

A curious feature of the crystalline is that the refracting power of the whole is actually *greater than that of the nucleus*. This seems paradoxical, but it can be understood by a reference to Fig. 40.

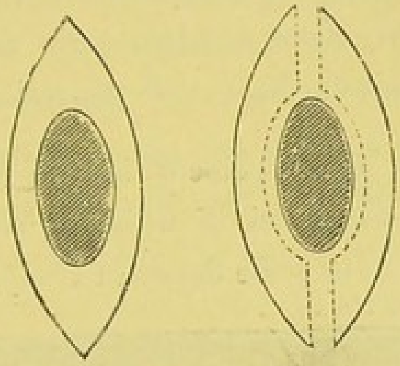


Fig. 40.

This figure is purely diagrammatic, and illustrates the influence of difference in value of n.

We may regard the crystalline lens as made up of three lenses, the convex inner one having a higher refractive index than the concave outer ones. Let us suppose for the moment that all parts are of the same index of refraction, that which is usually adopted as the total index for the purposes of calculation ($n = 1 \cdot 42$ Tscherning). It is evident that the outer concave menisci, when closed over the nucleus, will with it form a weaker lens than the nucleus would be if alone. Now let us see the difference by putting 1·412 as the index of the nucleus, and 1·40 as that of the outer layers, these being the figures indicated as probable by recent research.

Evidently, the lower index of the outer concaves will make them weaker, and they will not go so far towards neutralizing the central nucleus. If, then, the outer imaginary concaves have decreased in refraction more than the central convex we shall have a combination of greater power than if they were all of the same, but yet higher, index of refraction. We may illustrate this point by two combinations of glass lenses, one of — 8 D, + 30 D, and — 8 D, all of the same index of refraction, giving a resultant power of + 14 D; and another with, say, glass of a lower index of refraction for the convex, and a still lower index for the concaves, giving — 6 D, + 28 D, and — 6 D, and, therefore, a resultant power of + 16 D. So that by actually lowering the indices of all, in a similar manner to that exhibited in the crystalline lens, we get + 2 D more power. These figures are merely illustrative, and in no way represent the actual difference in the crystalline arrangements. The capsule of the lens may be neglected on account of its thinness, nevertheless, being a curved surface it must produce some slight refractive effect. After traversing the lens and entering the vitreous, light undergoes no further refraction. At first sight we might be tempted to regard the vitreous as a lens, with a considerable curvature where it adjoins the retina. This is not so, the curved posterior being coincident with the retinal screen.

Chromatic aberration is a defect present in the human eye, and is a natural consequence of the dispersion of white or any composite light. It has already been referred to in some detail in Chap. VI.

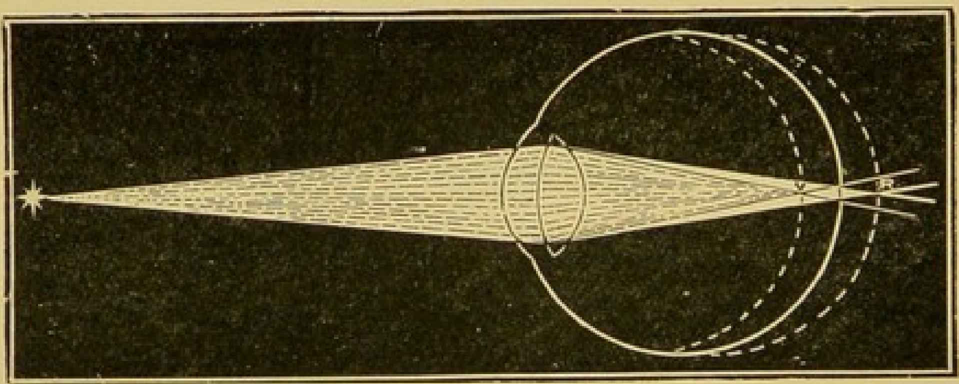


Fig. 41.

In this diagram, V is the focus for the Violet rays, and R for the Red.

Fig. 41 illustrates the way in which this aberration affects the retinal image. The eye naturally focuses itself for yellow light, this occupying a central position in the visual spectrum, and having the greatest illuminating power; thus the violet and red diffusion circles here coincide, and form a very faint purple border, but as purple is not a very luminous colour, the border is not noticed in ordinary vision.

The use of a purple glass, which only allows red and violet light to pass, enables us to distinguish the myopic eye from the hyperopic (provided no accommodation is used). A reference to Fig. 41 shows that the eye of long form, looking at a round source of light, will see a red centre with a violet border, and an eye of short form the reverse. This is sometimes used as a test, dark cobalt blue glass, which contains much red, or a combination of red and violet glasses being employed. It should be of round form to fit into the trial frame, and is placed in front of the eye at right-angles to the visual axis, a circular source of light, at a distance of six metres, being observed by the client.

In emmetropia a ring of purple is seen, but a hyperope will see a red circle with a violet or blue centre, while a myope will see a violet or blue circle with a red centre. It is known as the *chromatic test*.

The optical anomaly of internal reflection gives rise to a number of phenomena. In the first place the loss of light during passage through the lens system is great. We know that whenever light strikes the surface of a transparent medium reflection, as well as refraction, takes place, the proportion of each depending upon the angle of incidence, and the ratio of the refractive indices of the old and new media. Light striking the cornea in any direction will thus be partly reflected, and partly refracted, and if we place a luminous source, such as a candle, in front (but slightly to one side) of the cornea, we shall be able to see a distinct image of the flame due to the reflected light. This is the first loss of light. By close examination, and by varying the position, possibly, of the candle flame, images may be observed (Fig. 45), which are formed by the anterior surface of the cornea and the two surfaces of the lens. We may look upon these as *primary* reflections. Frequently, as has been mentioned, very faint images from the surfaces of the crystalline nucleus are visible.

This light, being reflected outwards, undergoes secondary reflection at every surface it meets, and is returned internally, in some few instances, causing annoyance in vision by forming *false or harmful images*. We will investigate one instance which will illustrate all.

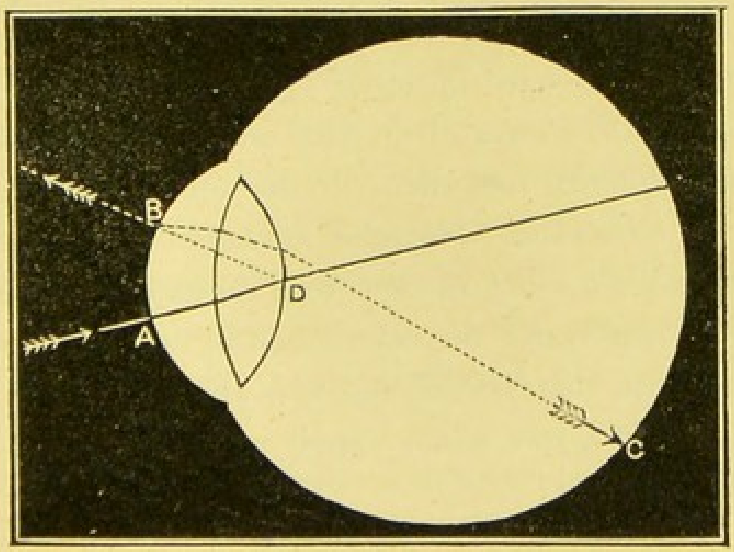


Fig. 42.

In Fig. 42 the direction of the incident light is shown by the path, or ray, A.

This undergoes several reflections, but the only one indicated is that from the posterior surface of the lens, although there would be others from the anterior and posterior surfaces of the cornea, and the front surface of the lens. The dotted lines illustrate the course taken after its primary reflection. Impinging on the cornea from within part passes out, and part is reflected back to the lens, through which it passes, and finally, meeting other paths from the object (not shown in the diagram), it comes to a focus just in front of the retina, being known as the sixth image of Purkinje. The portion which is refracted into the air by the cornea is Purkinje's fourth image, and is the one referred to above as coming from the posterior surface of the lens. The first image is due to reflection at the anterior surface of the cornea, and the second, smaller and almost behind it, is from the posterior surface. The anterior surface of the lens reflects the third (Fig. 45), and this image, with the fourth, was used by Sanson in the diagnosis of cataract, from which they are sometimes called Sanson's images. It is Purkinje's first image which becomes so useful in ophthalmometry. The peculiar structure of the crystalline lens is of great advantage in lessening the amount of reflected light, for had this been greater in the case of the sixth image it would probably have caused serious annoyance in general vision. The fifth image is formed by a first reflection from the anterior surface of the lens and a second from the anterior surface of the cornea, and is situated in the vitreous near the posterior surface of the lens.

The last of the ordinary optical imperfections is due to irregularities in the media of the eye. Reference has been made to the supposed regular astigmatism of the lens in some cases. But there is an irregular astigmatism of the cornea which conforms to no such rules as the regular variety does, different meridians of the cornea showing as many small differences in refraction. Irregular variations in the indices of refraction of the media explain some, the lens with its curious arrangement of sectors and fibres is responsible for others, and to such an extent does irregular astigmatism exist, that few, if any, eyes are free from it. To anyone not having this defect a star would appear in the sky as a point of light, and not as a radiate figure.

Entoptic phenomena (appearances due to structural or other defects within the eyeball), form a class by themselves. They are all images caused by shadows thrown upon the retina by various obstructions which light encounters in passing from the cornea to the retina. These images in ordinary vision are so faint, through diffusion, as to be neglected.. Being shadows they will be best seen when light within the eye is parallel, such casting the strongest shadows. Occasions are few when light is parallel within the eye, for such must diverge from the anterior focal point, which is only a trifle over half an inch in front of the cornea. Looking into the empty field of a microscope, or through a telescope at a white cloud, long strings of beads, hair-like bodies, and small specks seems to float about. These are known as *muscae volitantes*, and are shadows of substances in the vitreous humour.

We may make a useful experiment with a very small pinhole held at the anterior focus of the eye. A good light is essential, a bright opal gas globe answering well, or even a clear white cloud, if the eye can be protected from outside light. Looking through, we perceive a circle of light with finely serrated edges, which is an image of the pupil, the pinhole being too close to be visible, and by opening and shutting the other eye we get the expansion and contraction of this circle, due to concurrent movement of the pupils when light is admitted and shut off. All appearances with the entoptic pinhole are projected into the outer world; we see nothing as if it were in the eye. When the pinhole is moved a little distance away from the anterior focus a peculiar star-like figure comes into view, caused by the arrangement of the sectors of the lens, with consequent unequal refraction.

An observant person can by this method trace the course of a partial cataract in his own eye. The obstructions in the vitreous appear nearer the eye than the figure due to the lens, and frequently small bodies are seen beyond this, caused by corpuscles in the cornea or aqueous. Movement of the pinhole causes an apparent motion of some of the images, great in proportion to their distance from the nodal point of the eye, but the lenticular phenomena, being near it, are fixed.

There are certain congenital deficiencies of structure occurring occasionally, such as albinism, or the total absence of pigment from all parts (a partial state being not uncommon), causing *photophobia* and diffuse images, with lowered acuity, also coloboma of the choroid, where a tract of choroidal tissue is wanting, usually concurrent with a similar defect of the iris, with results akin to those of albinism, and, finally, the total absence of lens or iris, when in the former case accommodation is impossible and refraction abnormal, and in the latter photophobia and diffusion are exceedingly troublesome.

Summary :—

(*a*) No eye is free from physiological or optical defects.

(*b*) The optic part of the cornea corresponds fairly well with the size of the normal pupil.

(*c*) Astigmatism of the lens by incidence may affect the amount of the corneal variety.

(*d*) The various structures are rarely properly centered upon the optic or polar axis.

(*e*) Spherical aberration may be positive or negative.

Chapter X.

OCULAR MUSCLES AND MOVEMENTS OF THE EYES.

THE muscles which move the eyeball are all external to it, and are arranged in a group or system of six: four, known as straight muscles or recti, are placed almost symmetrically above, below, and at the sides, while two others are obliquely inserted on the eyeball nearly at right angles to the straight muscles. The names, superior, inferior, internal and external sufficiently locate the recti, and the two oblique are known as superior and inferior.

All these muscles are attached to the eyeball by fibrous connections called tendons, which have a wide insertion, so that any pull on the ball is extended over a considerable space. Not only so, but they are attached at a part where the sclerotic is thickened and strengthened, and where the ciliary body inside forms a circular mass, enabling this portion of the eyeball best to bear the tension. The recti seem to grasp the ball, being inserted a little in front of the middle portion, and run backward, as

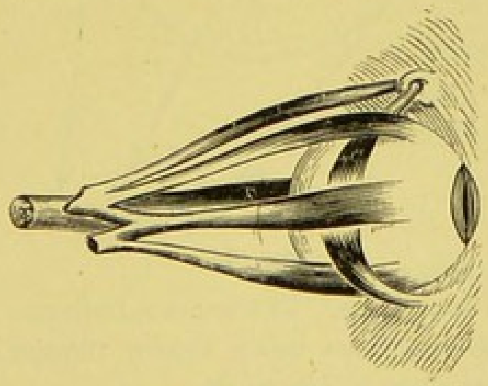


Fig. 43.

shown in the accompanying diagram (Fig. 43), becoming attached to the bony orbit. The superior oblique muscle is also attached there along with them, but to allow for the necessary direction of its pull, it passes through a tendinous ring fixed to the frontal bone above and in front on the nasal side, forming a kind of pulley, known as the *trochlea*. This muscle is peculiar in that it becomes temporarily tendinous where it passes through the loop. The inferior oblique is attached to the superior maxillary bone on the under and inner side of the eyeball. From appearances these muscles are arranged in pairs of opposites in position.

The position of insertion of the tendon of a muscle suggests the direction of its pull, and the function of such muscles as these being to shorten the length between the two terminal attachments, we can readily see, by their arrangement, in what direction each will pull the eye on contraction; but as the superior and inferior recti are not inserted exactly at right angles to the optic axis, they do not raise or depress the eye in such a manner that the apex of the cornea describes a straight line. The superior rectus, for instance, when it contracts, pulls the cornea upwards, and a trifle inwards, so that it requires the co-operation of the inferior oblique to correct this inward motion. Similarly with the inferior rectus and superior oblique. In fact the only two muscles which have an individual straight pull are the internal and external recti, and these differ from the others in their range of action.

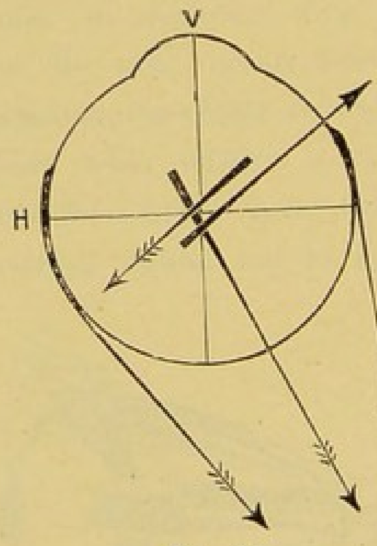


Fig. 44.

The left eye, from above. The arrows indicate the direction of pull, the muscular insertions being shown thicker. V is the visual axis, and H a line at right angles to it.

Details of length and size of these muscles will be found in Tables at the end of the book. The superior rectus is closely united with the sheath of the elevator muscle of the upper eyelid, a union which explains their association in action, and similarly the inferior rectus is associated with the lower eyelid. The four recti are inserted at distances from the cornea equal to 5, 6, 7 and 8 mms., easily remembered as the *spiral of insertions*, in the following order :—Internal, inferior, external, superior. These points of insertion of the muscle tendons are not the points at which the pull upon the globe is exerted, for each muscle clings to the globe over a certain distance (Fig. 44), known as the *arc of contact*, which varies for all of them with different positions of the eye. The pull would thus appear to be exerted just at the point where the muscle leaves the ball itself, but Tenon's capsule is so intimately connected with the muscles that it modifies the direction of pull very considerably, and much increases the difficulty of studying this part of the subject.

The superior recti of the two eyes always act concomitantly; we *must* raise both eyes together, and in depression the two inferior recti act similarly. The internal and external recti may act differently according to the varied requirements. If we turn the eyes to the right the external rectus of the right eye and the internal rectus of the left eye are pulling together. If, now, we look at a distant object in front, and then direct vision to a point much nearer, the eyes converge, consequently the two internal recti are contracting. It is evident how complex may be these combinations, and how curiously the eye is moved. In fact no parallel to these combinations of the lateral recti can be found elsewhere in the body.

The following table shows what muscles are concerned in the various movements.

STRAIGHT MOVEMENTS.

To Nasal side	Internal rectus.
To Temporal side	External rectus.
Upwards	Superior rectus and inferior oblique.
Downwards	Inferior rectus and superior oblique.

OBLIQUE MOVEMENTS.

Upwards and to Nasal side	Superior rectus, internal rectus, and inferior oblique.
Downwards and to Nasal side	Inferior rectus, internal rectus, and superior oblique.
Upwards and to Temporal side	Superior rectus, external rectus, and inferior oblique.
Downwards and to Temporal side	Inferior rectus, external rectus and superior oblique.

The structure of the external muscles is quite different from that of the small muscles inside the eye, and consists of the same fundamental parts as those of the limbs. They are built up of minute fibres, which by different treatments will divide lengthways into finer threads or *fibrillae*, or transversely into disc-like forms. Each minute fibre is inclosed in a sheath of fine membrane, the *sarcolemma*. Muscles of this kind are distinguished as voluntary, because they are under the control of the will, in contra-distinction to the involuntary kind, which are not so controlled. They are very sensitive, and if injured or overworked may ache, and they require rest and a plentiful blood supply to recuperate. They are kept in the best condition by exercise, and non-use may cause wasting or atrophy. Any defect in the fine nerve fibres running amongst their minute threads may cause paralysis, or failure to act, while an undue stimulation frequently causes spasm, or *clonic* contraction. They will do more work with medium than with small or great resistance to their pull. This is worthy of note, for we should almost expect the least resistance to show best results, as it is not so tiring to the muscle.

Muscles are normally active by stimuli passing to them through the nerves, but they also respond to electric currents applied directly. Tonicity of muscle is a state of contraction of a continuous description, and every muscle has a tone when in health, so that it is always slightly shorter than after death. Whether some local agency causes this tonicity, or whether the stimuli necessary for its maintenance arrive through the usual nervous tracts, it is difficult to determine.

The eyeball is placed in a bony cavity which it does not fill, the intervening space being packed with fat, forming a cushion. This arrangement is really a ball and socket joint, the ball being limited to movement in the socket formed by the fatty pads, no forward or backward motion being possible under ordinary conditions. As movement is limited to rotation, there is a centre for this 13·5 mm. behind the anterior surface of the cornea, and about 2 mm. behind the geometric centre of the eyeball. It corresponds fairly well with the centre of curvature of the posterior part of the eye.

The eyeball is invested by a capsule, which separates it from the masses of fat around, and provides the real socket in which, lubricated by a secretion, it moves. This is known as *Tenon's capsule*, and wherever muscles, nerves, or bloodvessels penetrate to meet the eye, it invests each like a deep collar. The important part, from the optician's point of view, lies just over the muscles, before they are attached to the globe. Here it is thicker than elsewhere, and it divides into two sections or flanges, which, when cut across, are Y shaped. The inner flange attaches itself to the eyeball, and runs to the cornea, being continuous with the conjunctiva of the sclerotic; the outer being attached to the margin of the orbit. This membrane is elastic throughout, as, indeed, is necessary with such a mobile organ as the eye.

Those portions attached to the orbital margins are known as the *check ligaments*, their function being splendidly adapted for its purpose, for they prevent retraction by the pull of the muscles, and also prevent the eye from being pulled round too far in any direction, their great elasticity forming a sort of brake, and avoiding the shock to the eye, otherwise inseparable from muscular contractions suddenly produced, and as suddenly arrested. Their greatest extensibility is about 10 mm., just as much as a muscle shortens for the greatest movement of an eye.

The external muscles have a dual function. They are designed for moving the eye or eyes, so that the field of vision may be changed from one location to another, and their movements are also arranged in such a manner that they may enable us to change the direction of the visual axes from points further off to points nearer to the eye, in what are practically the same fields of vision.

There is a certain position of the eye which is known as the *primary position*. We may define it as that assumed with the body and head erect, when the eyes are directed to the distant horizon, so that the visual axes will, for all intents and purposes, be parallel. Any other position which the eyes assume is known as a secondary position, and to change the eyes from a primary to a secondary position, contraction of some of the muscles is necessary, the number acting depending entirely upon the secondary position assumed, probably in most cases all six in each eye being called into play.

In the change from a primary to any secondary position there is a limitation to the movement of the eyes; they do not possess the power of making any swivel rotation. This may be put in another way. Supposing we regard the visual axis as an axis of rotation, we cannot, by any effort, cause the eye to revolve on this axis to any position whatever from the primary. This is *Listing's Law*, and may be stated thus :—Any movement from a primary to a secondary position is one in which the eye rotates round an axis which lies in a plane *vertical* to the visual axis, and passing through the centre of rotation. If, then, we imagine the eye cut in two through the vitreous, 13·5 mm. from the cornea, and at right angles to the visual line when in the primary position, such cutting would form the plane in which all possible axes of rotation would lie, in fact we might divide the plane in imagination like the protractor of a prescription form, and have a separate possible axis of rotation for every degree. Listing's law has some slight exceptions, but they tend to give the same results as the law itself. Note must be made that, whatever movement the eye makes from the primary position, this plane does not move. Owing to the pull exercised by the muscles on the sclerotic it has often been maintained that, acting in pairs, they tend by over exertion to produce astigmatism of the cornea, and therefore that undue pulling of the external and internal recti tends to produce astigmatism against the rule, while the pull of the superior and inferior recti would tend to produce astigmatism with the rule. The action of the obliques with the recti would tend to produce astigmatism in oblique meridians.

When the eyes are in the primary position we may say that there is parallel vision, and Dr. Lindsay Johnson, in his researches on the eyes of animals, has shown that only man and the monkeys have parallel vision with the power of convergence. In all other mammals the eyes diverge and in the lower orders this may be almost at right angles to the body length. In addition only man and the Simiae (true monkeys) have a macula, a fact which led him to state the *Law of the Macula* which is this :—All animals which possess a macula have parallel vision and the power of convergence, and have a circular pupil, and conversely all animals which have parallel vision and the power of convergence possess a macula.

In this connexion we may also quote from Le Conte (Sight) :—" A general view of objects in a wide field is a necessary condition of animal life in its higher phases ; but an equal distinctness of all objects in this field would be fatal to that *thoughtful attention* which is necessary to the development of the higher faculties of the human mind. Therefore the human eye is so constructed and moved as to restrict as much as possible the conditions both of *distinct* vision and of *single* vision. Thus in monocular vision the more elaborate structure of the central spot restricts distinct vision to the visual line, and focal adjustment still further restricts it to a single point in that line, the point of sight."

Summary :—

(*a*) Each eye is moved by a system of six external muscles.

(*b*) The insertion, or line of attachment of the tendon of a muscle to the eyeball, suggests the direction of its pull.

(*c*) The only two muscles which act in single pairs are the internal and external recti.

(*d*) Muscles in health are always in a state of tonicity.

(*e*) In moving the eye from the primary position to any secondary one there is no swivel rotation.

CHAPTER XI.

ACCOMMODATION AND CONVERGENCE.

FOR distinct vision a clearly defined and perfect image on the retina is necessary, and, when vision is distinct, the position of the object seen and its image on the retina are conjugate foci. This being so it is clear that some arrangement must exist within the eye for focussing images on the retina, seeing that we can get distinct vision, in an emmetropic eye, for objects like the stars, which are millions of miles away, and also for small objects within a few inches of the eye. From the time of the early writers on optics this has been recognized, and many have been the explanations offered. The facts are indisputable, but the character of its mechanism is a subject not yet satisfactorily elucidated.

Perhaps one of the best means of testing this power of adjustment is to view distant objects through a mesh, such as a window curtain. We find that we can get distinct vision of either the object or the meshwork separately, but not both together, and we experience a sensation in viewing the nearer object, a slight exertion, as of some muscular action. The exertion results in a greater convexity of the crystalline lens, and is known as accommodation. This increase in convexity can be shown by holding a candle flame a few inches from the eye and a trifle to one side, a darkened room and a little practice being necessary for success.

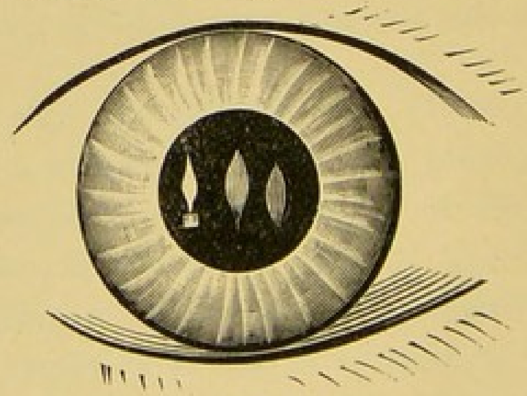


Fig. 45.

Images of a candle held to one side of the eye. They appear separated because of the position of the candle; the nearer the candle is brought to the visual axis, the closer they appear, until they coincide when the light is on the axis.

Three images are seen in the pupil, backed by the glow from the illumination of the interior. They decrease in order of brightness; the first, from the anterior surface of the cornea, being sharply defined and erect; the second, from the anterior surface of the lens, is dimmer, larger and also erect; but the third, from the posterior surface of the lens, is scarcely discernible, smaller, and inverted. If the candle be held much on one side, the first image will be in front of the iris, which then acts as a background. When the eye is adjusted from a distant to a near point the second of these images becomes smaller and alters its position, but we cannot detect any change in the other two. As the second is reflected from the anterior surface of the lens, and as an increase in the convexity of a surface lessens the image from it, evidently it is the anterior surface of the crystalline lens which becomes more convex during accommodation. A careful inspection of an eye when changing its look from a far to a very near point shows also that the pupil contracts during this alteration, and enlarges on reverting the look to a further object. These two movements, one of the lens, and the other of the iris, are the known facts of accommodation.

Helmholtz devised his phakoscope to show the increase in curvature of the anterior surface of the lens. In a box-like structure two prisms are arranged to double each image, the object being a white square, and a needle being placed so that vision may be adjusted for it as a near point. The anterior surface reflects two images of the square, which, on accommodation taking place, approach each other, the alteration in position being more evident than a mere change in size.

Every eye has what is known as a *far point*, or punctum remotum (written p.r.), real or imaginary, and a *near point*, or punctum proximum (written p.p.), always real. The near point is the nearest position to the eye at which, by the greatest effort, we can distinctly see an object such as a needle, without the blurring due to the formation of diffusion circles. The far point of the normal eye is at infinity, the only limit to distinct vision being the size of objects, as explained in Chap. VIII. The distance between the p.r. and the p.p. is the *range of accommodation*, and the power necessary to cover the range is called the *amplitude of accommodation*. We always express this amplitude in dioptres, for, if the ciliary muscle be paralysed in the emmetropic eye we merely have vision for infinity. If a +5 D lens be placed in front of the eye we find the near point is 20 cm. (about 8 inches) away. A + 1 D lens, similarly, would mean a near point of one metre. These are approximately the powers which would have to be added to the crystalline lens in a state of rest to adjust vision from infinity to the two near points mentioned. We may write this down as a formula : A (amp. of acc.) $= p - r$ where p is the power in dioptres required for near point adjustment, and r for the far point, but no power is required to adjust vision for the far point in emmetropia (or myopia), therefore, in these cases, $A = p$ (emm) and $A = p - r$ (my), while in hyperopia, the far point being negative, $A = p - (-r)$ or $A = p + r$.

It is important to note the relative positions of the far point in emmetropia, hyperopia and myopia. In the first it is at infinity, in the second it is beyond infinity or negative, being *behind* the eye, and in the third it is always within infinity. To make the far point of the hyperopic eye assume the same position as in emmetropia a lens must be placed in front of the eye, to cause the plane waves of light to converge, because such an eye can only focus convergent waves. The point to which these waves converge is the far point of the hyperopic eye, and so is coincident with the posterior focus of the correcting lens. Hence it follows that the higher the hyperopia the nearer is its far point to the back of the eye, always provided that no accommodation is being used.

Given the distance of the near point from the eye we can always find the power in dioptres by dividing 1 metre by that distance, or $A = \frac{100 \text{ cm.}}{20 \text{ cm.}} = 5$ D, the example taken above. A distance of 200 cm. (2 metres) thus requires one half the power required at 1 metre, or ·5 D. We may obtain the amplitude in practice by finding the strongest concave glass through which distant objects of standard size can be seen distinctly by the emmetropic eye, for this will represent the extra power gained by the greatest effort of accommodation.

Before pursuing this question further we must understand how accommodation is brought about, remembering that, although the facts of accommodation are well know and indisputable, the means by which the lens assumes its extra convexity are still in dispute. Nevertheless there are certain features upon which nearly all are agreed, and we may summarize as follows :— (1st). The anterior surface of the crystalline is the one which assumes greater convexity, the postering altering to a very slight degree. (2nd). The lens does not increase in volume. (3rd). The ciliary muscle contracts. (4th). The lens capsule and its attachment, or zonule of Zinn, plays some important, but disputed, part.

The present views as to the mechanism of accommodation may be divided into two groups, centering round (*a*) the theory of Helmholtz; (*b*) the theory of Tscherning. Helmholtz propounded his theory as merely probable, and although many disputed its details, it is the more generally accepted one. Tscherning's is of recent date, has found many followers, and has formed a nucleus for others on the same lines.

Helmholtz put forward the following explanation :—With the eye at rest the ciliary muscle is inactive, and the lens capsule is kept tightly stretched by the pull of the zonule of Zinn, or suspensory ligament, which joins it to the part near the muscle. As the muscle itself is fixed to the sclerotic by the ciliary ligament near the root of the iris, when it contracts it pulls the loose choroid coat, to which it is also attached, forward. By this shortening of the muscle there is a release of the suspensory ligament, which, communicated to the capsule, allows the crystalline lens to swell, on account of its inherent elasticity due to a peculiar curving of its fibres. This extra convexity of the lens, by increasing its refractive power, causes the eye to become accommodated for nearer points, the position of which is regulated by the amount of contraction of the ciliary muscle. By means of needles thrust through the sclerotic into the choroid Hensen and Voelkers, experimenting on dogs, noticed the opposite ends of the needle move backward when the ciliary nerves were stimulated, thus proving this important forward movement of the choroid.

Tscherning, by many elaborate measurements, claims to have established the following facts :—The amplitude of accommodation is greater for the centre portion of the crystalline lens than for the outer parts, consequently, during accommodation the anterior surface of the lens increases in curvature at the centre, while it is actually flattened towards the margins, forming what is called a *lenticonus*. This observation is supported by the structure of the lens, for the nucleus is denser, and the capsule being tightly stretched over the whole, when a pull or contraction is exerted on the zonule the harder central nucleus will cause a bulging of the outer layers, while the margins, having no such backing, would flatten somewhat.

The ciliary muscle, when it contracts, pulls the choroid forward, as Helmholtz maintains, but this is merely to support the vitreous, while the free part of the triangle towards the lens recedes, and so exerts a traction on the zonule of Zinn, which is communicated to the capsule.

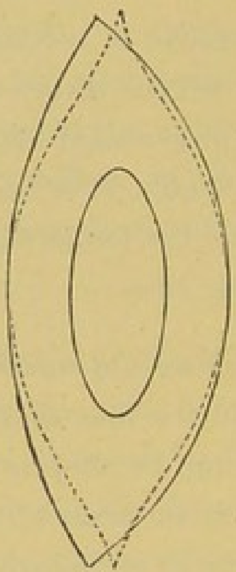


Fig. 46.

The lens at rest, and during accommodation, according to Tscherning. The central oval represents the nucleus. Dotted outline is the position during accommodation.

These are the two main theories of accommodation, and a few words on one of the latest outcomes of Tscherning's theory must conclude this part of the subject. Schoen has propounded a theory which places the principal event in accommodation in the traction of the choroid, but instead of merely supporting the vitreous, he adduces evidence to show that there is a consequent pressure, which, having only one outlet, viz : in front, transmits the pressure to the lens, bringing about much the same results as Tscherning's traction on the zonule.

As age advances the fibres of the crystalline lens harden, with consequent loss of elasticity to the whole lens, so that it cannot assume so great a convexity as before, evident whichever theory of accommodation we adopt. The change is gradual, and as a consequence the near point recedes little by little. One peculiarity of the eye is that it is fully developed, functionally, at so early an age as 8 or 10 years, and after that the crystalline lens may be regarded as decadent in power, although it still increases in size. At 10 years of age the near point is about 7 cm. from the eye, and the consequent amplitude of accommodation is $\left(\frac{100 \text{ cm.}}{7 \text{ cm.}}\right)$ 14 D.

The following table gives this amplitude for ages from 10 to 75 years.

Years	Amplitude in D	Years	Amplitude in D
10	14·00	45	3·50
15	12·00	50	2·50
20	10·00	55	1·75
25	8·50	60	1·00
30	7·00	65	0·75
35	5·50	70	0·25
40	4·50	75	0·00 (or ∞).

In all cases the corresponding near point can be found by dividing the metre by the number of dioptres, the result being expressed in centimetres. Thus at 20 years the p.p. is $\left(\frac{100 \text{ cm.}}{10 \text{ D}}\right) = 10$ cm., which shows a recession of the near point of 3 cm. in 10 years, but if we compare the ages of 45 and 55, we find a recession of 28 cm. in a similar period, and if this eye requires to read fine print at 13 inches (33 cm.) distance, it will be using $\left(\frac{100 \text{ cm.}}{33 \text{ cm.}}\right)$ 3 D of its accommodation, and at the age of 45, having only 3·50 D available, it has merely a margin of 0·50 D, which involves an effort, with consequent strain on the ciliary muscle. Shortly, even with the greatest effort, the near point cannot be kept at 33 cm., but will recede until such a margin is left as to allow some degree of comfort. At a certain point, however, small type will not have a sufficiently large image on the retina, so that to bring the near point closer, the accommodation must be aided by a convex lens placed in front of the eye. (Chap. XL).

We must next consider accommodation in ametropia, taking first hyperopia, in which state the eye is too short, light reaching the retina before it comes to a focus. The retina is thus within the posterior focus of the eye. Under these conditions the only light which could focus upon it would have to be convergent before entering the cornea, as already explained. The hyperopic eye, therefore, when viewing clearly any object, at whatever distance, is in a constant state of accommodation, for it needs some of this even to focus parallel light on the retina, the amount depending on the degree of the defect. Consequently, just this amount will have to be deducted from the amplitude of accommodation of an emmetrope of the same age to get the resultant p.p. of accommodation for the hyperope.

An example will illustrate this. Reference to the previous table shows that at 30 years the eye possesses 7 D amplitude of accommodation, and if it uses 4 D of this to obtain a well defined image of distant objects, it can only have 3 D left for focussing near objects, and consequently its near point will be $\left(\frac{100 \text{ cm.}}{3 \text{ D}}\right)$ 33 cm., or 13 inches from the eye. Such an eye reads fine print at 13 inches, but no nearer, and it will be using the total power of its lens, obtainable by the very greatest effort, a condition quite unbearable; whereas the emmetropic eye, having 7 D amplitude, would only use 3 D, with a reserve of 4 D, and consequently could read with comfort.

In the myopic eye the ball is too long, and parallel light will focus inside the vitreous, so that the retina is too far away from the posterior focus. If this light can be made sufficiently divergent upon entering the cornea, the focus will recede, and an image be formed at the macula. This can be done by a concave glass, incident parallel light becoming divergent on leaving the lens.

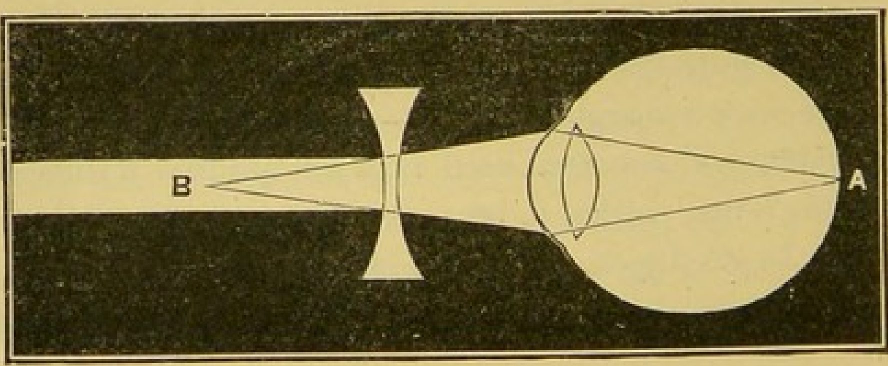


Fig. 47.

A myopic eye, showing the effect of a concave glass on parallel light. B is the apparent point of divergence of the wave after refraction by the concave lens.

Tracing the divergent wave backward through the lens to its origin, we see that this will be the far point of such an eye, the conjugate focus of the macula with the eye at rest. It will always be somewhere within infinity, and any point *further removed* would cause myopic diffusion circles on the retina. Myopes viewing objects beyond their far point 'screw up' the eyelids to lessen the diffusion circles, only allowing central rays, which have a longer focus than the marginal ones, to pass.

Supposing this eye has an amplitude of accommodation 7 D, and its far point is 50 cm. away, then its near point will be 7 D plus 2 D (the value of its far point), for in this instance the far point is like a secondary near point; in fact, it would occupy the same position as the near point of an emmetrope of about 53 years. Its near point is $\left(\frac{100 \text{ cm.}}{9 \text{ D}}\right) = 11$ cm., and it will be over the above age before it needs to use a convex lens for reading small print at 13 inches.

In regular astigmatism there are two principal meridians of the cornea, giving a maximum and a minimum refraction (Chap. IX.). To accommodate for light waves passing through the meridian of greatest refraction needs less exertion than for those passing through the least. How, under these conditions, does the crystalline lens act? It is thought by some that the ciliary has the power of varying its contraction for different meridians of the crystalline lens as occasion requires, in fact, an astigmatic accommodation, but there is not sufficient evidence to warrant this view. The more probable explanation is that accommodation is so adjusted as to make the various diffusion circles, formed by the varying refraction of the different meridians, about equal in intensity. Nevertheless, it seems likely that the position of the object viewed may have an influence. Looking at a row of vertical lines, such as trees would present, the eye would neglect horizontal ones, and accommodate only for the vertical, and vice versa.

In Chapter X. the primary position of the eyes was defined, and in that position the visual lines are parallel. The power of the two internal recti to turn the eyes inwards was also mentioned. To exercise this power the visual lines of the two eyes will converge, and the movement is known as *convergence. The power to exercise such convergence is called adduction*, and is exerted principally by the internal recti muscles.

There still remains a trifling resemblance between the position of the human eyes and those of animals. The visual axes of human eyes at rest diverge slightly, but the axes of the bony orbits diverge more. Before the visual lines reach parallelism from a state of rest they must converge a little (negative convergence). So that in measuring total convergence we have to add this negative convergence to the positive convergence from parallelism to the convergent near point.

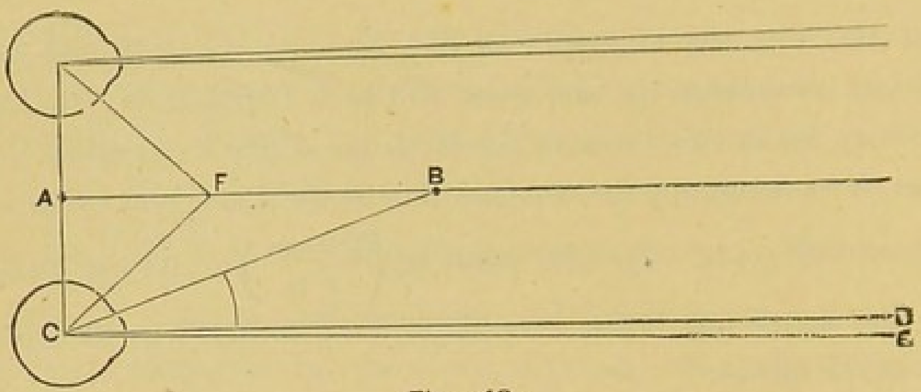


Fig. 48.

C D shows parallelism of the visual axes, C E the normal divergence, A B is supposed to be one metre, B C D is one metre angle.

As for distances above 6 metres the visual axes are parallel, the muscles are in the state of tonicity referred to in the last chapter, and this is known as *tonic convergence.*

When we have converged by any effort of the internal recti muscles, and then release them, the external recti contract, and pull the eyes back to a position of rest by *abduction*, the movement being *divergence*. But this does not quite exhaust the power of abduction, for when induced to their strongest effort by prisms, 'bases in,' placed before the eyes, the external recti are capable of still further diverging the visual lines. It must be clearly understood that adduction commences from the utmost limit of divergence, and extends to the nearest point possible, and abduction from the nearest limit of convergence to the greatest distance apart of the visual lines—they are coincident in extent, and opposite in direction.

There is a close relation between accommodation and convergence; *they are linked functions*, and disturbance of this relation is apt to be detrimental to perfect vision. Nevertheless, we can exercise them separately, for if a pair of concave lenses be placed before the eyes, accommodation must be used to overcome them for distant vision, but convergence is not used. If prisms, bases in, are placed before the eyes, convergence is prevented for a nearer point, but we must accommodate for such a point. Similarly, convex lenses, of requisite strength, obviate the necessity for accommodation, but we must converge. By the use of some drugs too, the ciliary muscle may be paralysed for near vision, but they do not influence the internal recti to any extent.

Convergence is measured in a similar way to accommodation. We can determine a near point, and knowing the far point, the distance between them is the *range of convergence*, and the power necessary to cover that distance is the *amplitude of convergence*. Just as the unit of accommodation is 1D, so the unit of convergence is one metre angle, or the angle formed between the visual lines of one eye, when the eyes are directed to infinity, and when they are converged to 1 metre on the median plane between the eyes, the angle being measured at the centre of rotation (Fig. 48). Convergence for 50 cm. will require 2 metre angles $\left(\frac{100 \text{ cm.}}{50 \text{ cm.}}\right)$, while for 2 metres half a metre angle will suffice $\left(\frac{100 \text{ cm.}}{200 \text{ cm.}}\right)$. It is well, in this connection, to note that in high degrees of convergence the eyes are generally depressed, and this also applies to accommodation, consequently these functions in such degrees are much easier exercised upon objects below than above the eyes themselves.

We can find the amplitude of convergence by the following method. Prisms, bases out, placed before the eyes viewing a distant flame, will cause the eyes to converge, and the strongest prisms which will allow the flame to give a single image will, when added together, give us the convergence from parallelism to the near point (called *positive convergence*). This is sometimes as much as 30° for each eye. We can find the number of metre angles by dividing by 7, thus $\frac{30° \times 2 \text{ (eyes)}}{7} = 9$ metre angles approximately.

The greatest divergence from parallelism may be measured in a similar way, but with the prisms, bases in, before the eyes. The strongest prisms which will allow single vision will, when added together, be a measure of this divergence, which is called *negative convergence*. They will be about 4° for each eye, so that $\frac{4° \times 2}{7} = 1$ metre angle. The amplitude of accommodation is thus about 10 metre angles. An inspection of Fig. 48, shows that the metre angle will vary a little with different interpupillary distances, but the differences are slight, and may be neglected for this purpose. Reference to Tables at end of book will show the variation between 50 mm. and 70 mm.

Landolt's apparatus for measuring the near point of convergence is simple and convenient. A tube of black cardboard, with a thin slit in the side, is placed over a candle, which is seen as a streak of light. Being brought towards the eye along the median plane it will at a certain point appear doubled. The distance of such a position from the eye, along the median plane, is the near point of convergence.

One consequence of the separate exercise of accommodation and convergence is that we get certain limits within which accommodation may be exercised without altering convergence, and other limits within which convergence may be exercised without disturbing accommodation. These are known as *relative amplitudes*. The relative amplitude of accommodation to convergence can be obtained by placing a light at a *given distance*, and finding the strongest convex and concave glass, with which it can be seen distinctly, the sum of the numbers indicating the power of the lenses used being the relative amplitude. Thus, if + 4 D and —3 D can be so used, the relative amplitude of accommodation to convergence is 7 D.

On the other hand, by looking at the same object, and finding the strongest prisms, 'both bases in' and 'bases out' added together, which may be overcome, without the light appearing double, we get the relative amplitude of convergence to accommodation.

Linked together as these two functions are, the exertion for a certain number of dioptres of the amplitude of one calls forth an equal number of metre angles of the other, presumably by equivalent stimuli from the nervous centres. But if, from hyperopia, a disturbance ensues, then a greater stimulus passes to the ciliary muscle than to the internal recti, with consequent greater accommodation than convergence, for the same point. Vision may still be perfect so far as visual acuity goes, but the headache, so characteristic of *asthenopia*, or *eyestrain*, is a direct result of the disturbed balance of accommodation and convergence. We may summarize thus :—In emmetropia accommodation and convergence for infinity are at zero, but for all distances within infinity both must be used. In ametropia accommodation will vary, but convergence is a fixed quantity for a given distance. Consequently in ametropia there is discomfort from want of harmony between the two.

Summary :—

(*a*) Equally distinct vision of far and near points is due to accommodation, caused by a change in curvature of the anterior surface of the crystalline lens.

(*b*) The limits of accommodation are the p.r. and p.p., the distance between which is the *range*, and the power necessary to cover the range is the *amplitude*.

(*c*) The principal parts concerned are :—The ciliary muscle, the crystalline lens, and the lens capsule.

(*d*) Presbyopia is caused by a lessening of the elasticity of the lens fibres, due to age, with a consequent gradual loss of power of accommodation, and recession of the p.p.

(*e*) In hyperopia accommodation must be used for vision at the p.r., leaving less available for the p.p.

(*f*) In myopia the p.r. is always within infinity, and the amount of accommodation needed for near objects is just so much *less* as in the emmetropic eye would be necessary to bring V from infinity to the myopic p r.

(*g*) Total amplitude of convergence equals total amplitude of divergence.

(*h*) Accommodation and convergence are linked functions.

(*i*) A limited range of either function is possible with the other fixed, the power necessary for this range of the one possible is known in each case as the *relative amplitude*.

CHAPTER XII.

BINOCULAR VISION.

FROM study of the two previous chapters it is evident that the various movements of the eyes are so ordered, that, by means of two retinal pictures, the outer world is presented to the mind in such a way that we shall judge each individual point, observed by both eyes, as having a single existence.

The totality of objects seen by each eye may be referred to in two different ways, subjectively and objectively. The whole of the sensations received by the retina of one eye is best defined as the *field of vision* or *visual field*, for that eye (Chap. VIII.); but the totality of objects seen is quite a different matter, for the objects are the starting places of waves which cause sensations, the one is the primary cause of the other. This, then, we may call the *field of sight*, or *field of view* (Fig. 49). The distinction has a certain importance, for an object moving in the field of sight, along the median line, may be practically motionless in the field of vision. Again, the sum of the two visual fields is greater than the field of sight. This apparent anomaly is worthy of explanation. Complete binocular vision is composed of three parts, illustrated in Fig. 49, the large curvature of which represents the horizon.

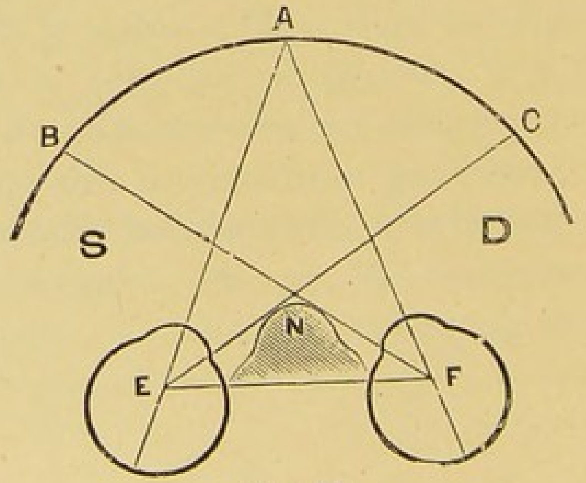


Fig 49.

E and F are nodal points. N is nose, and A point fixed.

The fields of sight for R and L eyes are limited by the nose, as shown by the lines F B and E C. Consequently, only the part inclosed by B A C N is common to both eyes, while the parts S and D are seen only by the L and R eyes respectively. B A C N is the binocular, S and D are monocular portions of the field of sight. These areas are determined by the prominence of the nose and other facial characteristics in each case, so that any object situated within the space B A C N will be presented to the brain as two separate series of impressions which are *never entirely alike*, except at great distances ; but objects in the spaces S and D will have merely single images to represent them ; in other words, vision is always monocular for these areas in the normal eye, and diplopia, or doubling of vision, cannot be produced. Vision of the central heart shaped space is similar to what would be given by a single eye in the median line of the head—the cyclopean eye of Hering.

The distinguishing feature of binocular vision is the production of the perception of *relief*, the difference between a simple photograph and a stereoscopic view of the same picture. With one eye only, the mould of a medal and the medal itself have much the same appearance, but with binocular vision the distinction is apparent. Relief is the perception of the third dimension in space. We may say that with monocular vision we only perceive height and breadth, but binocular vision gives us the impression of depth.

There are two conditions necessary for binocular vision. The one is that the two images of an object viewed shall fall on the two maculae at the same time, and the second, limiting the range of movement of the eyes, within which that condition is attained, is that parallelism or convergence is the position of the eyes.

No further evidence is needed to see that binocular vision is dependent on the motor muscles of the eye. Hansen Grut was the exponent of what is known as the *innervational theory*, explaining their movements. It supposes that in a normal eye, in a waking state, the muscles have a tonicity keeping them all equally balanced, and that every impulse which causes any muscle, or set of muscles, to contract, will allow the antagonistic muscle, or set of muscles, to relax to just the same extent, and there is evidently some curious nervous centre which governs this balance of the muscles, and also the associated movements of the two eyes. During sleep it is inactive, for we frequently experience diplopia when half awake, the amount and form varying at different times.

In Chapter X., Listing's law was explained as limiting all movements of the eyes. This limitation is necessary, not only that the particular object to which the visual lines are directed shall have its image on both maculæ, but also that surrounding objects shall appear singly in the field of sight, although they have images occupying different positions in the visual fields.

If we press the outer corner of one of the eyeballs with the fingers we produce diplopia, or double vision, but relaxing the pressure gradually, we find the images of objects re-unite. This shows that certain parts of the two retinæ are so united, or linked in vision, that when the image of an object falls on one, the other receives an image of the object also. They are known as *corresponding* or *identical points*, but, as previously explained, this field of sight common to both eyes is the only portion capable of furnishing such duplicate images. If any movement of the eye displaces an image to another position, we get diplopia; a prism before the eye will produce it, unless the motor muscles concerned are strong enough to place the eye in a new position where the image will fall on the same spot as before.

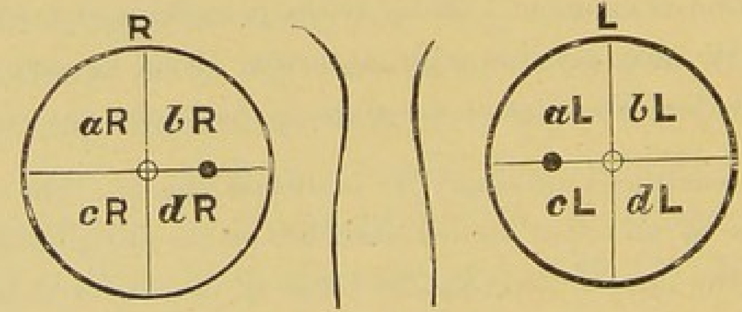


Fig. 50

Fig. 50 is a diagrammatic view of the two retinæ, marked R and L, the entrance of the optic nerves (blind spots), being shown as a dark space, the light circle locating the fovea. Two imaginary lines, vertical and horizontal, are called *lines of separation.** It is obvious that the quarters *a*R, *b*R, *c*R, and *d*R correspond in position to *a*L, *b*L, *c*L, *d*L, the upper halves of R to those of L, and similarly with the sides. But, examining the structural arrangements, we observe that it is the nasal parts of R which correspond with the nasal side of L, and similarly with the two temporal halves.

* Recent researches of Volkmann show that these vertical lines converge slightly downwards.

Suppose, now, that we direct vision to a horizontal line about six inches long, drawn upon a piece of white paper, and held nine or ten inches away. Small "crosses" are placed at the centre and at both ends, the central one being fixed by the two eyes, which are opened and closed alternately. The visual lines pass from this cross through the nodal points, until they fall on the foveas of both eyes. The cross at one end can be made to fall on the blind spot of the R eye, with the L closed, and that at the other end on the blind spot of the L eye, with the R closed, by a little adjustment of distance. In each case a cross will fall on the retina at a distance from the macula equal to the space between it and the blind spot, but the same cross will not fall on both blind spots. That seen by the R eye is the one which falls on the L blind spot. The corresponding points do not agree with the structural arrangement of the retina. A glance at the diagram shows how important is Listing's law, for, had the eyes a swivel rotation, the lines of separation would move from the vertical, and converge upwards or downwards, the horizontal moving to the same extent. Not only so, but the whole retina would share in the movement, and images would not fall on corresponding points, with a resultant diplopia. It will be found that ordinary ocular movements follow Listing's law in the interests of binocular vision, but—as in nearly all physiological laws there are some exceptions—so there are small variations from that to which Listing's name has been given. During convergence, and also when the head is bent down towards either shoulder, there is a trifling swivel rotation of the eyes, possibly two or three degrees, but even these, especially that during convergence, are directed to the same ends, namely, the maintenance of binocular vision.

The movements of convergence and divergence, explained in the last chapter, may now be supplemented by *sursumvergence*, or the movement of the eye upwards, and *deorsumvergence*, or downward motion; the former being caused by contraction of the superior rectus and inferior oblique (*supraduction*), and the latter by the inferior recti and superior oblique (*infraduction*). Disturbance of the balance, and consequent normal action of these muscles, results in diplopia, just as in the other case.

In every instance where one eye moves there is a movement of its fellow, a fact not always apparent, for if we ask anyone to fix a point with both eyes, and then place a second point in the visual line of the R eye, there would seem to be no necessity to move this eye when both eyes fix the second point. Close observation will, however, show that it receives a double innervation, first, one of association, because of which it turns a trifle to the right, and a second one of convergence, which brings it back into its previous position.

It is quite impossible that all objects in the field of sight should fall on corresponding points, and when we fix one position, the image of which will, of course, fall on the maculæ, there are merely a number of other objects lying within certain geometrical figures or areas, which are seen truly in this way. The figure or area which would include all these is called a *horopter*; it takes the most varied forms, alters probably with every direction of the look, and is at times very complicated. In every instance it is such a figure as is best adapted to the needs of vision. A single instance will show this. When the eyes assume the primary position the horopter is practically the surface of the plane on which we are standing. For all other objects seen in indirect vision outside this horopter there would thus seem to be a slight diplopia. It is, however, no disadvantage, but merely aids, in some cases, the production of the stereoscopic effect, while in others one image is suppressed. This is known as *physiological diplopia*. Under conditions which produce diplopia, other than that of indirect vision referred to, we find the brain exercises a selective power with regard to the two images; for if these were of equal distinctness, the consequent confusion would be almost unbearable. There is a suppression of one image in many cases, often especially obvious in anisometropia where the refraction of the two eyes is very different. The refractive errors are the primary cause of the diplopia in most of these instances, and the brain must at some period decide which shall be the seeing eye for the future. The images formed in the discarded eye are neglected, efforts for their improvement are insensibly abandoned, and vision gradually becomes more or less monocular.

Two angles, formed by the visual lines with each other, and with the optic or polar axis, need explanation in connection with this subject. When the visual lines converge to a point they form an angle between them, known as the *optic angle*; it is twice the size of the angle of convergence from parallelism (the corresponding metre angle), for each eye, and for the same degree of convergenee will vary a trifle with different inter-pupillary distances, as can readily be seen from the diagram.

Angle a (called alpha), is that formed by the visual line and the optic or polar axis, at the nodal point of the eye. This is the result of the fovea not being exactly at the posterior pole of the eye ; in cases where it is so placed there is no angle a, as the visual line and optic or polar axis will coincide. Usually the macula is a little distance to the temporal side from the posterior pole, and as the angle is measured at the nodal point, a short eye will give a larger angle than a longer one. Hence, in hyperopia, this angle is sometimes 7° or 8°, and the eyes appear to be divergent, giving rise to *false strabismus*. On the other hand, the long myopic eye may have a small angle, none at all, or even a slight negative value, owing to the visual line meeting the retina inside the optic or polar axis, so that the eyes appear to be converged slightly.

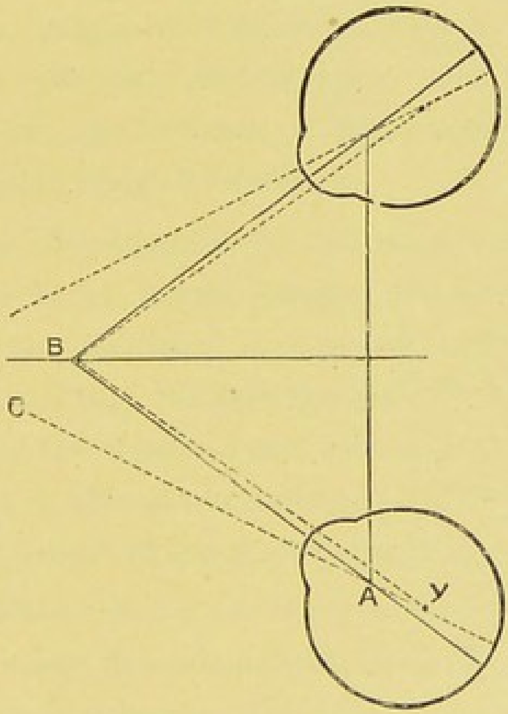


Fig. 51.

The optic angle is at B, alpha at A, and gamma at γ. A is the nodal point. γ the centre of rotation. C A optic or polar axis. B A visual axis.

The angle γ (gamma) is unimportant. It is formed by the optic or polar axis with a line drawn from the centre of rotation to the object looked at. It is thus always smaller than angle a in the same eye, the difference being equal to the small angle formed, at the point viewed, by the visual line, with the line joining that point to the centre of rotation.

Summary :—

(*a*) The field of sight is composed of three parts, the central heart-shaped one of which is devoted to binocular vision.

(*b*) The images of an object viewed by each eye are never entirely alike, except at great distances.

(*c*) Such images, in direct vision, must fall on both foveas.

(*d*) Motor muscles, in the waking eyes, are kept balanced by their natural tonicity.

(*e*) Corresponding or identical points are areas of the retina upon which images of an object simultaneously fall in binocular vision.

CHAPTER XIII.

HOW WE ESTIMATE SIZE AND DISTANCE.

THE judgments of size and distance by means of the human eye are very complex, and call for activity of nearly all the muscles, and the keenest perceptive powers. We may summarize the factors in the estimation as follows :—(*a*) Size of retinal image. (*b*) Innervation necessary for adduction or abduction. (*c*) Differences of the two retinal images. (*d*) Experience. (*e*) Accommodation. (*f*) Clearness of near, and haziness of distant objects. Before considering these factors seriatim, a few words are necessary on our judgment of direction. This is more accurate, probably, with one eye than with two, and in many people it seems not unlikely that one eye becomes predominant in this respect, the other following it, as it were, to maintain binocular vision.

There is a general law of projection for all objects seen, whether they are in the external world or merely entopic, and situated on or within the eyeball itself. Every sensation is projected outwards from a point of the retina along the visual line, through the nodal points of the eye. Thus, an area of the retina to the temporal side will be projected outwards towards the nasal side. It is almost unnecessary to add that, in binocular vision, two corresponding points of the maculæ must be projected to exactly the same point of origin.

The size of the retinal image depends entirely upon the distance of the object, and the dioptric arrangements; the longer the eyeball, the greater the distance of the nodal point from the retina, and consequently the larger the image, as in myopia ; hyperopia, being due to a short ball, will produce smaller images. Where diffusion circles exist these will blur the retinal impression, and tend to misapprehension of size. In the emmetropic eye, however, with an object of a certain size, if the retinal image increases we judge that the object is approaching, and if it decreases, that it is moving away. Suppose we know that objects compared are in a fixed position, such as the letters of Snellen, at 6 metres distance, then, if the retinal image of one is twice as long as that of another, we judge the size of the letters in the type to be equally proportionate to the respective images.

Our perceptions of size based upon the magnitude of the retinal image are likely to be deceptive, and give rise to optical illusions, through judgments of the mind entering into the estimation. In the illustration shown, although B and C are equidistant from A, they do not appear so, because the interposition of other objects causes the mind to exaggerate the size of A B, through directing its attention to the number of smaller spaces. There are many of these illusions, due mainly to a combination of retinal perception and mental judgment.

We cannot at all accurately estimate distance merely by this change in size of the retinal image on the approach or recession of objects. We see a ship, perhaps ten miles away, we see it again five miles away, and although we know perfectly well the laws which govern the apparent size at certain distances, unless we have some means of recording the magnitude in the first position, and of comparing it with that of the second, we cannot tell accurately what distance away it is.

Again, the size of the retinal image is liable to be entirely misinterpreted, through experience of the other factors being united with it. A very ready means exists of showing this. Looking intently at a white circle in a good light for some considerable time, and then directing vision to a movable white or light coloured screen, we see on it a black circle, known as an after image. If the screen be moved backwards this increases, but if forward, it decreases in size ; tilting the screen will cause it to appear oval. It is evident that the retinal image does not alter in size during the movements, but the mind, by associating it with the variations in distance and position, causes the varying judgments. Knowing that an object further away must be larger than a nearer one, to give the same sized retinal impression, the mind judges the after image larger, a similar reasoning explaining the diminution on approach. The same illusion exists in our estimate of the size of the sun or moon, when near the horizon, and when high in the heavens, for we judge the sky immediately over our heads to be much nearer than at the horizon, where we have a wide expanse of the earth for comparison.

Fig. 52 shows how the deception arises. Being seen under the same angle, but apparently further away, the sun or moon appears larger. The inner circle shows the actual angular size much exaggerated, and the ellipse shows the apparent angular sizes in the two positions mentioned. Moreover, scarcely two of a number of observers will compare the apparent size of the moon to the same measurement, for while one may liken it to the size of a coin, another may describe it as one or more feet across.

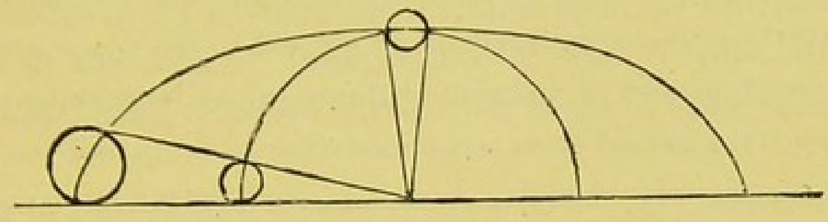


Fig 52.

Diagram illustrating the apparent sizes of the sun at noon, and when on the horizon.

The innervation necessary for adduction and abduction is a most important factor in estimation of distance. It was at one time thought that the amount of contraction of a muscle necessary to turn the eye, and the motion of the eyeball, furnished the means for estimation. But observations, in cases of paralysis, show that it is the innervation—the exertion or effort—what we may call the nervous-expenditure, which gives this. For objects on the median line adduction or abduction only will be called into play, as they approach or recede. When they move to lateral positions an associated movement to the left or right must be made, together with adduction or abduction, if they also approach or recede. This judgment is very exact, and, although by various means we may deceive the eye, so to speak, as by placing prisms in front, yet it is astonishing how soon the judgment is corrected.

The differences of the two retinal images helps to give us the ideas of relief and solidity. Holding an object further away from the eye than the near point, and viewing it with each eye alternately, two different images of the object are formed on the two retinæ. It is possible to place a sheet of paper edgeways before the eyes, so that each eye will see a different side, and at any distance within several feet the struggle between these two images is very curious, when both eyes are used. It is rare that such objects in this position are presented to us. At all usual distances the two images blend to give the idea of solidity, but the exact means by which this is effected is still the subject of controversy.

Accommodation being, partly at least, a muscular act, we might suppose that the exertion necessary to bring vision from a remote object to a nearer one would furnish us with sensations from which we could judge the space through which the origin of the visual line had travelled. But it is evident that such a function is quite unsuitable for this purpose, for out of the whole amplitude of accommodation only 1 D is necessary to bring vision from infinity up to 1 metre distance from the eye, so that the great part of the exertion of accommodation is devoted to the space within which we have physical means of judging distance, quite independently of the eye. The information gained from accommodation is altogether too indefinite for usual distances. In monocular vision accommodation must, in certain directions, play a greater part, but the indefiniteness of the judgment may be observed, by using one eye only, in endeavouring to pour water from a jug into a bottle.

Experience plays a part in the judgment of size and distance. With non-success and repeated trials memory is called into play, and illusions of the eye are corrected more or less quickly. The haziness of far objects is a feature which all artists represent on canvas, the surest proof that the eye usually recognises objects as very distant, because of their indistinct appearance. Irregular astigmatism is probably the cause of some of it, in much the same way as it affects the images of the stars. Atmospheric influences doubtless account for the rest.

Judgments of size and distance are interdependent. Acquainted with the one, we are influenced by it in our estimation of the other. If we see a *well known* object, such as a horse, under a very small angle, giving a very small retinal image, we immediately conclude that it is a great distance away, although, through an optical illusion, it may be quite close. The illusion of the after image, described earlier in the chapter, also illustrates this.

Many experiments may be made with similar explanations. A square sheet of white paper placed upon a dark coloured table, and the gaze directed to it at an angle of 45° or thereabouts, is recognised as a square, but the after image developed in a short time, when looking at a blank wall, causes us to see a black figure, which, taking the form of the retinal image, appears as an oblong with its short side vertical. The eye judges the paper on the table to be square, owing to the interdependence of size and distance, for we know that the one edge of the paper is nearer to us than the other, and correct the oblong retinal image mentally.

Summary :—

(*a*) One eye is frequently the directing eye.

(*b*) Every retinal sensation is projected outwards along the visual line.

(*c*) The size of the retinal image depends upon the distance of the object, and the dioptric arrangements of the eye (distance of the back nodal point from the retina). It is apt to cause illusions.

(*d*) The innervation necessary for adduction and abduction is a most important factor, but accommodation is not.

(*e*) We obtain the idea of relief, or solidity, partly from the differences of the retinal images in binocular vision.

(*f*) Judgments of size and distance are interdependent.

CHAPTER XIV.

QUALITATIVE PERCEPTION OF COLOUR.

IN Section 1 of this book the nature of white light and its component colours, each of a definite wave length, has been described, and we may here summarize by saying that in the qualitative perception of colour we have to consider sensations produced by light composed of undulations having a wave length between 0·35 μ and 0·8 μ.

The character of each of these colours depends on (*a*) the wave length, (*b*) the amplitude of the wave length (intensity), and (*c*) the freedom from admixture with white light itself. So that we describe colours as having *hue*, *intensity*, and *purity*, (*tint*, or *saturation*). Intensity depends upon the quantity of energy imparted at the source; a spectrum from direct sunlight giving more intense colours than one from an artificial light. In the solar spectrum colours near the centre (yellow and green) are more intense than any others, and comprise about one half of the whole in quantity of light, red coming next, and violet last. The colours in a prismatic spectrum of white light are pure, but in ordinary use we are accustomed to various pigments, all of which reflect a certain percentage of white light, and as these are not saturated or pure colours we cannot obtain by artificial means their exact spectral hues.

A highly trained eye has a really marvellous perception of colour, the retina receiving a different sensation with a variation of 0·001 μ for the wave-length in the green portion of the spectrum. Discrimination is, however, much less in the outer regions. It is said that in the tapestry works of the Gobelins, near Paris, there are 28,000 shades of wools which the trained workers can tabulate and use. In such a case none are ever pure hues, the saturation is incomplete, and there are a great number of combinations. The ordinary wools used as a test for colour blindness are of such shades as these; that is, they vary in *hue* and *purity*. Under such a hue as red there would be a great range of tints, from carmine to pale pink; all are of various degrees of saturation, or freedom from admixture with white light.

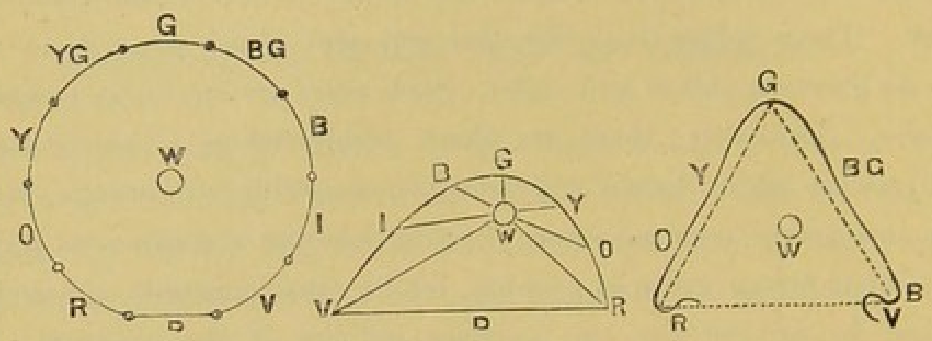
Although all colours of the spectrum, mixed in due proportion, produce white, it may also be obtained by blending pairs of spectral colours properly chosen. In fact, if we regard the spectrum as having a red side and a blue side, we may find a colour from the one, which, by means of optical appliances, will produce white when mixed with a certain colour from the other. These follow in order, for red and bluish green form white, as also do greenish yellow and violet. Such pairs are known as *complementary colours*. Evidently, there are many combinations of two colours which will produce white, for the red fades imperceptibly into orange, and this in turn into yellow, our sensations of colour forming a continuous series. But the central colour green is peculiar, for its complementary colour is purple, formed by mixing the two extreme colours of the spectrum. There is reason for supposing a spectral purple actually to exist beyond the violet, but owing to the fluorescence of the retina it is not visible, at least, as purple.

Although these pairs of complementary colours will each form white, they do not produce the same intensity as a combination of the whole of the spectral colours ; to obtain this we should require the sum of the intensities of the whole possible complementary colours in the spectrum.

The ordinary pigments of commerce must not be confounded with colours of the spectrum. Mixing yellow and blue pigments gives green, but combining yellow and blue spectral colours gives white. Pigments absorb the complementary colour, and give out the one which designates them, so that the blue pigment absorbs orange (yellow and red), as seen from Newton's table, while the yellow, mixed with it, takes the blues and violet ; evidently green is the only remaining colour of the white light falling on the mixture.

Newton, Helmholtz, and Maxwell, have constructed tables of colours which illustrate this and other points.

Newton's table is the simplest, being a circle except for a chord at the base which indicates purple. White, as the total product, is placed at the centre. A point between two colours indicates the merging of one to another, so that we obtain a representation of the continuous series. Colours opposite to each other are complementary. If we join a colour to white, the saturation decreases as we approach white. If any two colours be joined by a straight line, the intersection of this line with another one passing from any other colour to white will indicate the result of the mixture, and its purity. The mixture being in an *inverse ratio* to the ratio giving by the partial lengths of the chord from the point of intersection.



NEWTON'S Table. HELMHOLTZ'S Table. MAXWELL'S Table.

Fig. 53.

Maxwell's table is much more complicated than Newton's, and was constructed specially with regard to the equation of colours. A few remarks on the figure must suffice. Red, green, and blue (wave-lengths 0·630 μ, 0·528 μ, and 0·457 μ, respectively), are the standard colours, one at each angle of an equilateral triangle, curves being drawn about this to represent certain facts. Only colours within the triangle, namely, white and a certain intensity of blue and red, can be produced by mixing the three standard colours. All outside have a little less purity than those in the triangle, which indicates according to Maxwell that we cannot, by any proportionate mixing of these colours, produce any perfectly pure standard colour, but, if we mix any two colours on the same side we obtain a colour with as much purity as the spectral colour corresponding, while mixture of colours on opposite sides gives less purity, having a strong admixture of white. There is, however, little doubt but what Maxwell's standard colours were not exactly correct, as suggested by Helmholtz, for Sir W. Abney has succeeded in obtaining perfect matching.

The table of Helmholtz was specially designed to illustrate the apparent brightness of any two complementary colours joined by a straight line passing through the white. Their nearness to the white indicates this.

From a study of Maxwell's table we conclude that at least *three primary colour sensations are necessary to produce white.* At first sight this seems contradictory to the existence of complementary colours, but a casual glance at Newton's table shows that in every case of these pairs of colours we find one of the pair is really composed of two primary ones, red being complementary to green-blue, and so with others.

At the present time there are two theories of colour-vision which have received most attention, known as the Young-Helmholtz, and Hering theories.

The former was enunciated by Young and modified by Helmholtz. It supposes, as the three primary colours, red, green, and violet. For each of these colours a separate nerve fibre is imagined, so that by stimulation of all three white is produced, and by various combinations, with varying stimuli for each fibre, all colours can be evolved. Thus, when the eye experiences a sensation of yellow it is really a compound sensation, due partly to the stimulation of fibres sensitive to red and partly of fibres responding to green, the particular hue being given by the amount of stimulation of the two sets of fibres, the yellow approaching the red or green in accordance with the intensity of the stimulation of either colour. No such triple arrangement of fibres can be found in the retina, nor is it absolutely necessary to substantiate the theory.

Hering based his theory on the fact that the human eye fundamentally distinguishes four colours as different from any others, red, green, yellow, and blue having nothing in common, but such colours as orange, violet, and purple suggesting combinations of others. White and black he gives a place apart. The colours are arranged in three pairs, each one in a pair complementary to its fellow, white to black, red to a green shade, and blue to a yellow shade. Each of the three pairs is supposed to act on a separate visual substance, the colour of longer wave-length in each pair 'breaking up' or *dissimilating* its visual substance, and the one of shorter wave-length 'building up' or *assimilating* the material, but while two of the supposed substances are influenced by light of any wave-length, only to different extents according to the wave-length, the one corresponding to white-black is influenced only when white light (light comprising all wave-lengths) falls upon the retina, and then the red-green and yellow-blue substances are quiescent. That a substance sensitive to light, the 'visual purple,' does exist in the retina, we know; but this substance cannot account for colour vision, for in the human retina it exists only in the rods, while the end organs of vision in the region of the macula (the most sensitive portion of the retina for colour vision) are *cones*.

The phenomena of complementary colours may be studied by what are known as *negative after images*. Coloured patches or lights and a white background are required. The eye fixes the colour for 20 or 30 seconds, and then fixes any part of the background. An image is seen of the same shape as the object, but of the complementary colour, a red patch giving a bluish-green after image, and yellow one of a bluish tint. This seems to indicate the presence in the macula, or perhaps the brain, of some substance or substances which become exhausted, so to speak, for the one colour, and when the image is projected outwards it is seen of the complementary colour.

Other experiments tend to prove that the colour sense is due solely to the fact that the cones are capable of responding in a different manner to light of varying wave-lengths. The chief phenomena of colour vision may perhaps best be referred to under three headings :—1.—The Purkinje effect. 2.—The yellow-spot effect. 3.—The effect of non-achromatism.

The Purkinje Effect.—It was discovered by Purkinje that the intensity of sensation increases and decreases more rapidly for red than for blue light, for the same variation of luminous intensity of the object. As has already been stated, the rods respond most freely to light of that wave-length which produces, at high illuminations, the sensation of green ; while the cones respond most freely to light in the yellow region of the spectrum, and since it is known that as the illumination is reduced beyond a certain point the rods begin to act while the cones become less sensitive, it follows that, if equality of brightness is obtained for, say, red and blue, at a particular illumination as this is *increased* so will the eyes become *more sensitive to red*. Also as the illumination is *decreased*, so will the eyes become *less sensitive to red*, for in this latter case an excess of rods over cones is employed as compared with the former excess of cones over rods. So that although this is a colour phenomenon, it results not from an alteration in the colour perception at different illuminations, but from the fact that the rods and cones have not their maximum sensibilities in the same region of the spectrum. At high illuminations this phenomenon will not be noticeable, for then the rods are practically blind (saturated), and cone vision predominates.

The Yellow-spot Effect.—When we equalise the brightness of two small surfaces, one red and one blue for instance, while standing at a distance of about half a metre with moderate illlumination and then slowly walk away, keeping the eyes fixed upon the surfaces, it is noticed that while the red surface retains almost its original brightness, the blue one rapidly decreases, and if we recede far enough it fades away altogether. This phenomenon of colour vision is quite distinct from the Purkinje effect, for it occurs at high illuminations. To seek an explanation we must realize the variables in the problem. They are :—(1) Alteration in the size of the retinal image; (2) Change in the accommodative power of the eye; and (3) The effect of the non-achromatism of the human eye in conjunction with accommodation. The effects of the last two may be neglected, and it would seem, therefore, that the alteration in the size of the retinal image is the chief, if not the only cause which produces the disappearance of distant green and blue objects. The yellow spot, on account of its colour, absorbs the shorter wave-lengths of light, and this absorbing power increases towards the fovea centralis; hence, as the retinal image gets smaller and smaller (as we recede), green and blue objects will be seen with greater difficulty. Experiments made by Sir Wm. Abney on the absorbing power of the yellow-spot region support this explanation.

The Effect of Non-Achromatism. Because the eye is not corrected for chromatic aberration, when accommodation is in use for near work it will require less effort to focus for blue than for red, and therefore blue objects will be more readily seen. For distant work, however, a small effort of accommodation will enable red to be seen, but blue objects will require a reduction in the power of the crystalline lens for them to be clearly focussed upon the retina. This will be impossible, so that distant blue objects will appear blurred in comparison with other coloured objects. So that in near work for detail revealing purposes, a green or blue background is the best, while for distant objects a red background is preferable. Definition is impaired if the conditions indicated are not complied with. This effect is noticeable with a constant sized retinal image, and must not, therefore, be put down as a yellow-spot phenomenon, although the one is doubtless intimately connected with the other.

Daltonism, or colour-blindness, is a deficiency of the eye with respect to colour-vision. Vision, in ordinary persons, is *trichromic*, so-called from its three primary colours, but in cases of colour-blindness is usually *dichromic*, being limited to two of these. The most usual form of the defect is the confusion of red and green, these generally appearing as a greyish colour. Looking at the spectrum, two colours only are seen, separated by a dull grey interval situated in or near the green; towards the red end colours have a yellowish appearance, while the violet end is described as blue. When asked to match red such persons frequently choose a green, and when the one colour is bright they will often place a dark shade of the other alongside it, an indication that the light acuity also is affected. The greyish appearance of so many objects which they look at is doubtless due to a strong admixture of white in nearly all colours of natural objects.

From the results of tests made on colour-blind persons the light sense has been found to be subnormal without exception, the Weber-Fechner law by no means holding true. It is also possible to train colour-blind persons to differentiate between the colours *for which they are colour-blind*, and to assign to each its correct name.

Colour-blindness may be congenital, or acquired, as in toxic and tobacco amblyopia (see page 131). We may also meet with cases of partial defect, where colours appear dull and of low intensity. Holmgren's test for colour-blindness consists of a series of wools of various hues and tints; these must be used in a good light, without their names being called over to the client. First a very pale green is presented, with a request for other wools to be chosen which appear similar in hue. The readiness with which this is done is an indication of the acuity of the colour-sense. If greys or fawns are chosen, colour-blindness is established, while hesitancy is indicative of a lowered acuity (colour acuity). A rosy purple is next used. In cases where blue or violet are chosen to match this there is a deficiency in colour-vision for red, while green or even grey being selected, indicate green-blindness. Finally intense red is placed before the client. Green and brownish wools of a dark tint are taken by the red-blind, but light reds and browns indicate green-blindness.

Colour-blindness, as here described, is that type of defect which the optician will most often encounter, but is only one form of the deficiencies of colour-sensibility which may exist in the human eye. It is evident that the subject of colour-blindness has an important bearing upon the two principal theories of colour-vision already referred to. Neither of the two theories will explain the whole series of phenomena due to colour-vision, and various additions to each have been suggested from time to time for the purpose. Both theories have numerous adherents, and the whole subject must still be regarded as one needing much further investigation.

Summary :—

(*a*) The various sensations of colour are caused by undulations meeting the retina, with a different wave length for each colour.

(*b*) The attributes of colour are :—(1) Hue. (2) Intensity. (3) Purity, tint or saturation.

(*c*) Complementary spectral colours are pairs which form white when mixed together.

(*d*) Three primary hues are necessary components in a complementary pair of colours to produce white.

(*e*) A negative after image gives the complementary colour to that of the object.

(*f*) The cones are the end organs of colour vision.

(*g*) The non-achromatism of the eye causes a difference in the visual acuity for coloured objects at different distances.

(*h*) Colour-blind persons are usually dichromic, whereas normal colour vision is trichromic.

(*j*) Daltonism is always accompanied by deficient light acuity.

CHAPTER XV.

EFFECTS OF ACCIDENTS AND OPERATIONS ON EYESIGHT.

IN this chapter we propose to deal briefly with those accidents and operations which have definite and well marked effects upon the subsequent visual acuity in the affected organs.

Taking the ocular tissues in the order in which they naturally present themselves for our consideration, and starting with the outer covering of the eyeball, the ocular conjunctiva, we find that the chief accidents to which it is liable are those produced by :—

(1). The impact and lodgment of foreign bodies, such as particles of coal, ashes, small fragments of chaff, or dust.

(2). Actual wounds, such as scratches, lacerations, or penetrating injuries of deeper character. These latter of course always involve concomitant injury to the deeper lying tissues.

(3) Burns and scalds, such as may be caused by fire, chemicals, water, steam, etc.

All these accidents are the cause, primarily, of considerable pain and inflammation, but generally it may be considered that those superficial injuries which involve damage to the conjunctiva alone do not cause any permanent impairment of vision.

Burns, however, whether by chemicals or fire, are much more serious, and frequently result in more or less permanent obscuration, due to certain minute irregularities of surface formed in the course of healing, and caused largely by the contraction of the tissue in the act of cicatrization. For the maximum of injurious interference with **V.** it is obvious that such opacities and scars would have to be situate upon that area of the conjunctiva which is opposite to the pupillary aperture. In other words, these blemishes would not affect vision unless they lay in the path of waves of light entering the eye.

Operations upon the conjunctiva pure and simple, apart from the removal of foreign bodies, &c., are surgical feats needed in comparatively few conditions, such for example as the removal of pterygium, and with these we have no concern.

Accidents to the cornea are very similar in most respects to those of the conjunctiva described above, and consequently they may be classified similarly :—

(1). Injuries by foreign bodies.
(2). Denudations of epithelium.
(3). Penetrating wounds,
(4). Burns and scalds.

All these are similar in their effects on V. to what we find in conjunctival injuries, but are much more serious in character. There often occurs very severe inflammation of the cornea, and this may end in permanent opacity, with great injury to vision. By 'denudation,' we refer to partial loss of corneal epithelium, due mostly to injury caused by the contact of some sharp edged body, which has, so to speak, *scraped* the corneal surface. An injury of this kind might very well be inflicted by a finger nail. Serious possibilities are associated with an accident of this character. Wounds of the cornea in general fall naturally either under the head of injuries of this type, or of the more penetrative form of wound. If a corneal wound is of such a character that the corneal wall is completely perforated, the aqueous humour will escape from the eye, and the edges of the iris may become entangled in the wound. Under favourable conditions the aqueous humour is quickly replaced. If the wound is still more deeply penetrative the crystalline lens may be injured, with consequences which we shall discuss a little later. Even the entire eye may be inflamed and undergo destruction. The danger of complication from corneal wounds is therefore considerable, and serious.

Burns and scalds upon the cornea have much the same effect as on the conjunctiva. If slight and superficial, even though of considerable extent, they are not usually followed by permanent opacities, although more or less irregularity of surface is likely to be produced. If the burns are deep and severe their effects in these respects are marked. Injuries caused by lime and gunpowder are probably the most disastrous.

Operations upon the cornea are performed by surgeons in many diseases which are out of our province. It is sufficient to note that the result of many of these is a certain regular flattening of the cornea in a direction generally at right angles to the direction of the incision made during the operation. This produces a condition of astigmatism, which is prone to change considerably with the lapse of time. It is usually greatest shortly after the operation, and decreases in amount, from month to month, for some little time. Minor operations for the removal of small foreign bodies have but slight effects of this kind, so slight, as a rule, that in most cases no noticeable reduction in vision is thereby produced.

Accidents to the iris take the form of :—

(1). Penetrating wounds.
(2). Lodgment of foreign bodies.
(3). Rupture of the outer attachment, or of the sphincter.
(4). Displacement, or total separation from its supports.

It should be noticed that wounds of the iris always cause some amount of bleeding, which for a time greatly interferes with vision, and prevents examination of the part.

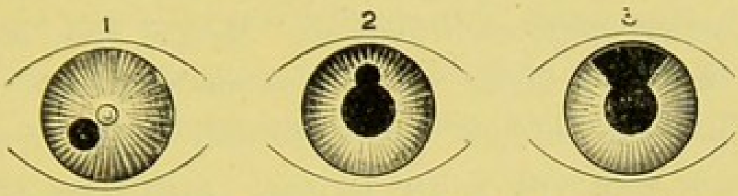
Complications from corneal and other sources frequently cause serious trouble. This is usually inflammatory in character, and may be so severe as to lead to the ultimate destruction of the eye.

Ruptures and displacements of the iris are caused chiefly by severe blows upon the eye, such for instance as those from a fist, cricket ball, champagne cork, or other projectile. If the ciliary attachment is ruptured, then, owing to the formation of a secondary pupil at the free margin, there will probably be monocular diplopia, and great confusion of vision, while rupture of the sphincter pupillæ produces an incurable mydriasis, probably because the muscle is unable to contract properly after such an injury, coupled with the inevitable loss of tone which follows. The effects of a condition of mydriasis are well known.

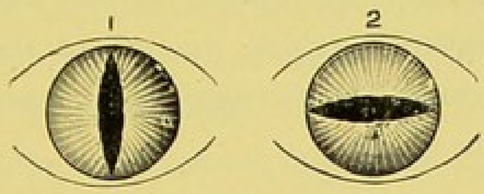
Displacements of the iris always point to some very severe shock to an eye, and are likely to be accompanied by other injuries (not always at first apparent) to the other tissues and structures of the eye.

The chief operations performed upon the iris are *iridectomy*, which is the removal of a portion of the iris, and *iridotomy*, which is the operation for creating an artificial pupil merely by slitting the iris. In both the shape of the pupil is peculiar, and the action of the sphincter pupillæ is destroyed.

After such an operation the acuteness of vision is most likely to be lowered considerably, and the largely increased diffusion of light upon the retina becomes a source of annoyance and confusion to the patient. Astigmatism is also caused, as previously explained, by the healing of the inevitable corneal incision.



Iridectomy : 1—For occlusion of the pupil.
2—Preliminary to lens extraction.
3—For glaucoma.



Iridotomy for occluded pupil from iritis, following lens extraction.
1 Vertical. 2 Horizontal.

Fig. 54.

Iridectomy is a rather common operation, and is done for many reasons besides the production of an artificial pupil, a matter of great importance where there is a dense opacity over the area of the natural pupil, interfering very greatly with vision.

Iridotomy is only done when the crystalline lens is absent. the result in this case being attained by the natural stretching of a simple slit or incision made in the iris.

Injuries to the lens are due either to a penetrating wound or to a severe blow. In the former case, the ultimate result is what is known as a traumatic cataract. The same condition may result from a blow upon the eye, causing a rupture of the lens capsule, and so admitting aqueous humour to contact with the lens substance. The usual effect of a severe blow upon the eye is a luxation or dislocation of the lens. This may be slight, or it may amount to a complete displacement. The effect of this accident upon the sight is most disastrous. Among the results may be counted monocular diplopia, loss of accommodation, varying refraction—in the same eye—in different parts of the pupil, and irregular astigmatism. Moreover, a dislocated lens usually becomes, sooner or later, opaque.

The only operation which is performed upon the crystalline lens is the one for cataract. This consists in the removal of the opaque lens by one method or another. The effect, of course, is to greatly reduce the refraction of the eye so treated.

An eye previously emmetropic becomes highly hyperopic, whilst eyes originally hyperopic become very much more so. Myopic eyes, unless they have previously been very highly myopic, become hyperopic, although if the degree of previous myopia was sufficiently high, they may be left emmetropic, or even with a low myopia. Such cases are comparatively rare. In addition to the refractive change brought about by the removal of the lens, accommodation is entirely lost, and there is produced the corneal astigmatism before mentioned. If the cataract has been removed by needling, or discission, which consists in the admission of aqueous humour to the lens substance through needle punctures in its capsule, then astigmatism does not result.

After a successful operation, and subsequent correction of the refraction by glasses, vision is sometimes as good as 6/5, but is usually much less, and may be only 6/36, or even 6/60. The retinal images are calculated, in an eye previously emmetropic, to be about one-third larger, after the operation, than before; so that in aphakia, an apparent **V**. of 6/9, would be equal to an ordinary acuity of approximately 6/12. This occurs because the eye, after the lens is removed, is reduced to a simple refracting surface, and the position of the nodal point is altered, in consequence, to a greater distance from the retina than before (Chap. XXI.).

For a few weeks after operations such as described dark glasses are usually worn. The correction of the resultant refraction should never be attempted until all redness and irritability of the eyes, consequent upon the operation, have disappeared.

Foreign bodies entering an eye may lodge in the vitreous humour, and are always a very great source of danger, while blows upon an eye may cause hæmorrhage into the vitreous, with consequent impairment of vision. They may, likewise, cause serious reflex inflammations. Rupture of the choroid, with serious impairment, or even destruction of vision, is caused by a blow upon an eye. The choroid is also liable to injuries from penetrating wounds, and from foreign bodies which may find access through either the cornea or sclerotic. Rupture of the choroid almost always causes considerable hæmorrhage, as it is abundantly supplied with blood vessels. The ultimate effect upon vision of a rupture of this membrane depends upon the position and extent of the injury done. It may be but slightly impaired, or, on the other hand, very grievously affected. No glasses will remedy the defect of vision caused by such an accident.

Blows upon an eye may also cause inflammation, detachment, or rupture of the retina. These consequences are always very serious, and often result in permanent, and sometimes immediate loss of vision. Here, again, glasses are of no use.

Injuries to the choroid and retina, opacities in the lens and vitreous, and foreign bodies within the eyeball, are detected by the use of the opthalmoscope.

Operations upon the external muscles of the eyes are performed for the purpose of removing the deformity known as squint. The operation is of twofold character. It may be accomplished by the tenotomy (or cutting) of a too short muscle, or by the advancement (or shortening) of one considered too long, or by .a combination of both methods. It should be clearly understood that no operation for squint has any corrective effect upon errors of refraction, and optical corrections necessary before operation are still more necessary afterwards, to prevent recurrence of the squint. In every case of successful operation for squint the personal appearance is much improved by the removal of the deformity, but a true cure, in the optical sense of the term, i.e., the restoration of perfect binocular vision at all distances and in all directions, is rarely, if ever obtained.

Summary :—

(*a*) Injuries to the conjunctiva are painful, but not often serious.

(*b*) Injuries to the cornea may leave opacity or astigmatism.

(*c*) Injuries to the iris may lead to loss of the eye.

(*d*) Operations upon the iris may cause permanent mydriasis.

(*e*) Accidents to the lens may cause cataract, loosening, or displacement.

(*f*) Blows upon an eye may cause irreparable injury to lens, choroid, or retina.

Chapter XVI.

BODILY ILLNESS AND OCULAR DISEASE.

GENERAL diseases of the body are well known in many cases to result in some affection of the eyes, and on the other hand certain affections of the eyes are taken as direct evidence of the presence of diseases of the body or brain. Further, many otherwise obscure symptoms can be successfully traced to their source by a painstaking examination of the eyes. It is evident then, that there is considerable relationship between affections of the eyes and disease in other parts of the body. The choroid and retina are both extremely delicate structures, the former especially is highly vascular, being in fact a close network of fine capillaries. Such structures immediately reveal disturbances of circulation brought about by disease of heart, kidneys, or brain, and as no other structures in the body like these are available for inspection, it is obvious that many such diseases are first accessible to observation by inspection of the interior of the eye, where their earlier symptoms may be first seen.

We will consider briefly only the commoner of such diseases as are known to have marked effects upon the condition of the eyes, and consequently have injurious results upon V., discussing first the general constitutional diseases that most commonly produce changes in the eyes.

Anæmia. This very common disease, if severe, results in malnutrition of the retina, which may be followed by optic atrophy and even ultimate blindness. With proper medical treatment in the earlier stages sight may often to a large extent be restored. Conical cornea is a condition which some writers believe to be often due to the general malnutrition consequent upon anæmia.

Diabetes. In many persons diabetes is a cause of cataract, which in form is similar to the ordinary senile type, except that the opacity of the lens is usually somewhat more diffuse, and is very apt to vary with the bodily strength and general condition of the patient. Diabetes often causes retinal hæmorrhages, and may cause neuritis and optic atrophy. Change in the amount of sugar in the urine at times causes changes in the refraction of the eyes, and such may arise with somewhat startling suddenness. Paralysis of accommodation occasionally occurs in diabetic cases. Sometimes direct vision is defective for the colours red and green, and such instances are likely to be mistaken occasionally for cases of tobacco amblyopia, a condition we shall discuss in a subsequent chapter.

Gout. This disease is blamed for almost every conceivable form of ocular trouble. Amongst the more common results of a gouty condition may be mentioned iritis. We find also inflammations of the choroid, retina, and optic nerve ascribed to the same influence. Chronic simple glaucoma is said to frequently occur amongst gouty people, and senile cataract is held by some writers to be usually initiated by a gouty diathesis. In old people slight inflammations of the cornea and conjunctiva are considered to be of gouty origin.

Heart Disease. The subject of heart disease is so complicated in its relationship to affections of other organs that we shall not enter into its possibilities; sufficient to say that disease of the valves of the heart, which is a very common heart affection, is believed to be present in all those cases where sudden and permanent blindness is caused by embolism of the central retinal artery. Temporary failure of sight is frequently heard of in people who are subject to heart affections, and it should be noticed that if the attacks of temporary blindness are of frequent recurrence they may lead to permanent loss of sight, optic atrophy generally ensuing from such attacks. Engorgement of retinal veins from heart disease is very likely to result ultimately in serious mischief.

Kidney Disease. The chief affections of the eyes resulting from diseases of the kidneys are albuminuric retinitis, retinal hæmorrhages, and uræmic amblyopia. These may often be looked upon as consecutive stages of one and the same condition. The two first are recognisable by the ophthalmoscope, and when found along with albuminuria *are always of most serious import.* It is seldom that a patient lives two years after albuminuric retinitis is observed.

Rheumatism. The affections of the eyes caused by rheumatism are much the same as those caused by gout, but experience seems to point to rheumatism causing a mild form of cyclitis rather than iritis. As rheumatism is a frequent cause of heart disease it is easy to see, from what has been said in a preceding paragraph, that the secondary effects of rheumatism may be very grave.

Scrofula. The precise nature of this disease is somewhat difficult to define. It is, however, considered to be closely allied to tuberculosis in character, and is a common cause of external diseases of the eyes. These are inflammations of the eyelids, conjunctiva, or cornea, and are generally associated with some unhealthy condition of the body.

Brain Disease. Optic neuritis may be caused by all forms of organic disease of the brain, and if such disease is suspected, and the presence of optic neuritis is proved, it confirms the diagnosis. Brain disease may cause abnormal conditions of the pupils and ocular muscles, and also contraction of the fields of vision. Optic atrophy generally follows upon optic neuritis, but in some cases it may occur without a previous neuritis. Retinal hæmorrhages and other vascular affections are frequent consequences of apoplectic seizures, and are usually accompanied by paralysis of various ocular muscles.

Spinal Cord. Affections of the spinal cord are said to be made manifest at an early stage by failure of vision, caused by what is termed grey atrophy. Frequently such cases show also a weakness or paralysis of some of the ocular muscles, Specific affections of the pupils are also proved to be diagnostic of well known spinal troubles.

Epilepsy. With this dreadful affliction there may be lowered visual acuity, and contraction of the fields of vision before or after an attack. It is commonly believed that epilepsy predisposes to cataract. In certain cases probably eye-strain has produced an epileptic condition, which has been cured by corrective lenses removing the nervous disturbance caused by the defect and its accompanying asthenopia.

Hysteria. Amblyopia, or even complete blindness of one eye, is not uncommon from hysteria. It is believed that eye-strain may in neurotic persons be a cause of amblyopia.

Migraine. Periodical sick headache is often accompanied by much disturbance of vision, flickering clouds and zig-zag flashes of light being amongst the curious phenomena described by persons suffering from this complaint. There seems to be no doubt that a great many cases formerly considered to be pure megrim are now believed to be due, in a large degree, to eye-strain. Such cases are partially, if not completely, cured by wearing accurately fitted refractional corrections.

Neuralgia. When occurring in the fifth nerve neuralgia is often an accompaniment of failure of sight caused by neuritis of atrophy. It is likewise frequently an accompaniment of glaucoma.

St. Vitus' Dance. In children this disease is sometimes accompanied by a corresponding muscular affection of the eyes, although chorea frequently exists without any such complication. Eye-strain is believed by some oculists to be the great predisposing cause of this disease during youth. It is sometimes asserted that the correction of any existing optical defect will cure many cases of chorea.

INFECTIOUS DISEASES.

Diphtheria. This disease may attack the mucous membrane covering the eyes, and lead to the destruction of the cornea, but under ordinary circumstances, and with proper precautions, this does not happen. What does almost inevitably follow a bad attack of diphtheria is a decided paresis, or even a paralysis of accommodation. This usually comes on with convalescence. It is first noticed when the patient is recovered sufficiently to use the eyes for reading. Such a condition may last several weeks, and disappears gradually with returning strength. Squint is not uncommon as a consequence of this and other debilitating diseases, where bodily weakness calls for very great effort to induce the requisite accommodation. This reacts upon convergence, producing an excess which it is impossible for the invalid to restrain.

Influenza. This comparatively modern disease often causes a weakness of accommodation, and consequent asthenopia. In some cases where great prostration has followed, optic atrophy ensuing has seemed to have a direct connection with it. Incipient cataract has been noticed to develop more rapidly after an attack of influenza, and even glaucoma may have been caused by it in some cases.

Measles. The consequences of measles are, primarily, photophobia and lachrimation, with more or less conjunctivitis. Secondarily, there may be corneal ulceration, or troublesome asthenopia. Squint often follows in hyperopic children, from the weakening of the powers of resistance, particularly should the attack of measles occur about the time when convergent strabismus usually manifests itself. It is a matter of common observation that an attack of measles seems often to be the forerunner of squint in an eye which previously showed no deviation. Children developing squint after measles are in a very great majority of cases markedly hyperopic.

Scarlet Fever. In common with some other forms of eruptive fever this disease sometimes causes complete temporary loss of sight. Such an occurrence is believed to be due to complications involving the kidneys, and producing uræmic poisoning. As in all other weakening diseases convalescence is likely to be accompanied by paresis of accommodation, which generally disappears as strength returns.

Whooping Cough. When the cough is very severe, and the straining great, ocular hæmorrhage is likely to occur, causing some temporary diminution of vision; or if in such a case the optic nerve is involved, it may end in optic atrophy and consequent blindness.

Other infectious diseases worthy of note are herpes, and erysipelas, the latter being specially dangerous when the orbit is involved.

Erysipelas is said to cause glaucoma, though it is questionable if this has been proved. Inflammation of the brain membranes may be a consequence of erysipelas.

Idiopathic Diseases affecting the eyes, are those which have the quality of arising spontaneously, and are not referable to some other diseased condition of the body. We will briefly consider those which are of interest to us as opticians, and which we are likely to meet with in our daily work because they have detrimental effects upon vision.

Cornea. The cornea is subject to severe inflammations and ulcerations, which often result in nebulæ or leucomæ, vision being correspondingly lowered or annulled, as the case may be, by the nature and position of the opacity.

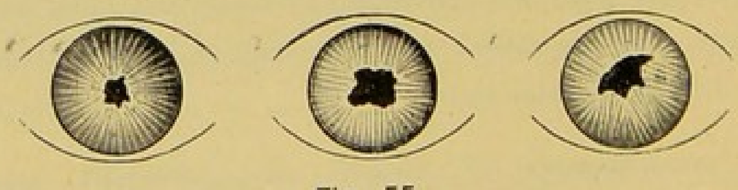


Fig. 55.
Iritic adhesions with varying pupillary apertures.

Iris. With this membrane inflammation is the chief trouble. Its results are adhesions to the lens capsule, which may be permanent, or possibly a deposit of patches of iritic pigment thereon. Adhesion to the cornea may also occur, or there may be complete occlusion of the pupil.

Lens. Disease which affects the lens is manifest by opacity of its substance, its capsule, or both. There are many forms of cataract, but opacity various in degree, extent, and position, is the essential characteristic of them all. Cataract is recognised by ophthalmoscopic examination, or by focal inspection. No treatment is of any real use, operation being the only resource.

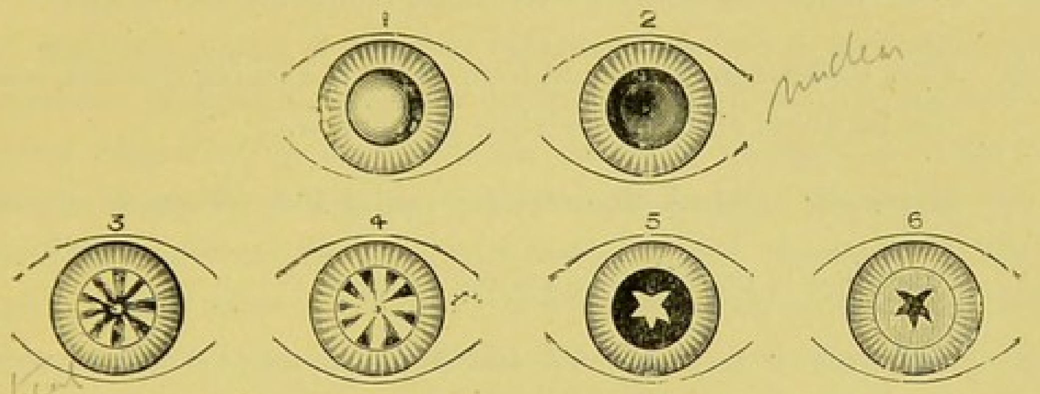


Fig. 56.

Pupil dilated, and the same opacity viewed, (i).—By reflected light.
(ii).—By transmitted light.

1 and 2. Nuclear Cataract. 3 and 4. Cortical Cataract.
5 and 6. Posterior polar Cataract.

Vitreous Opacities are likewise detected by ophthalmoscopic examination, and are usually due to some general constitutional disturbance. Their effects upon V. depend entirely upon their character and position.

Choroiditis. This inflammation most frequently causes no acute pain, and can only be diagnosed by inspection with the ophthalmoscope. It is a serious disease, and usually its only subjective symptom is a reduced visual acuity.

Retinitis. This disease, similarly, can only be determined by careful ophthalmoscopic examination. Its subjective symptoms are very vague. It is chiefly indicated by reduced or misty vision.

Glaucoma. This is perhaps the most dreaded of all the commoner diseases of the eyes. It may be acute and very painful, or insidious and painless. We find reduced visual acuity, contraction of the visual field, halos of colour around points of light, pulsation of retinal arteries, cupping of the optic disc and increase of ocular tension, noticeable to the touch of a practiced finger. Some or nearly all of these symptoms may be absent. A fact to be noted is the failure of accommodation with consequent apparent rapid increase of presbyopia. Glaucoma rarely occurs in persons under forty years of age.

Summary :—

(*a*) Bad sight may be due to the indirect effects of bodily disease.

(*b*) Sudden blindness may be associated with heart disease or brain affection.

(*c*) Acute infectious diseases often cause temporary loss of sight.

(*d*) After diphtheria, fever, and some other weakening diseases, weakness or paralysis of accommodation is common.

(*e*) Hyperopic children often develop squint after an attack of measles.

(*f*) Operation is the only remedy for cataract.

(*g*) Glaucoma is most serious, and suspicious cases should be sent to an oculist.

Chapter XVII.

EFFECTS OF ALCOHOL, TOBACCO, DRUGS, &c.

WE find, as a matter of practical experience, that there are certain defective conditions of sight of occasional occurrence, which are due, not so much to actual disease of the eyes, or to the results of accidents, as to the harmful effects of sundry habits or employments, drugs or medicines. In many cases the symptoms are so very remarkable and characteristic that each has a special effect on vision, which is universally regarded as diagnostic of a particular cause. These ocular conditions—not correctible by lenses—are known technically as *amblyopias.* When caused by the effects of alcohol, tobacco, drugs, etc., they are further denominated as "toxic amblyopias," which signifies blunted conditions of sight, due to the effects, more or less pronounced, of some form of poison. Foremost among these is alcoholic amblyopia, caused by the excessive use of stimulants. It is believed to be due to a wasting of certain fibres of the optic nerve, with consequent secondary effects upon the retinal structures. Alcoholic amblyopia is made manifest by lowered visual acuity, of a fluctuating character, affecting both eyes. The course of the disease is insidious and slow. If neglected, vision goes steadily from bad to worse, until sight becomes considerably injured. The remedy lies in total abstinence from alcoholic drinks, with the use of good nourishing foods and tonics. In well marked cases normal vision can rarely be restored. The condition is very apt to return if the use of alcohol is resumed. A certain degraded class of tipplers, who for cheapness drink methylated spirit, become easy victims. This vile fluid contains a large percentage of a particularly toxic substance, known to scientific men as methylic alcohol, or wood spirit. The drinking of this poisonous compound has been known to cause complete blindness, which, under proper treatment, may be partially remedied, but in some cases has, after partial recovery, become permanent. This may possibly have been due to a return of the habit of spirit drinking. Some few years ago cases of amblyopia were reported from America, presumably caused by the drinking of essence of Jamaica ginger as a stimulant and pick-me-up. In some instances blindness was said to have quickly ensued. Various reasons were assigned, and the harmless ginger was, for a time, credited with all kinds of toxic qualities. Investigation, however, tended to show that the cases in question had occurred after the use of an essence, in the preparation of which methylated spirit had been improperly employed, so that the presumption now is that all these were really cases of toxic amblyopia from the use of methylic alcohol.

Tobacco amblyopia is a still more familiar form of trouble. It is a rather frequent occurrence amongst men of middle age, but earlier in life is comparatively rare, and amongst females is practically unknown in this country. It is considered to be due to slowly progressive wasting or atrophy of the optic nerve, or of certain of its fibres, brought about by definite inflammatory conditions produced between the eye and the brain, in that region of the optic nerve known to anatomists as the retro-bulbar portion.

The symptoms of tobacco amblyopia are a gradually increasing reduction in the acuteness of vision in both eyes. The patient is often otherwise out of sorts, and more or less nervous and sleepless. The fundus, when examined by the ophthalmoscope, shows no distinctive signs. The patient often describes his sight as "dull," or "misty," a bright sunny day being more trying than a dull one, and especially so when looking at distant objects. Vision is frequently worse towards night. In the centre of the field vision is worse than for the outer portions, and is found to be especially defective for the colours *red* and *green*. The condition may be produced by smoking, chewing, or snuffing tobacco, and occurs chiefly in those who are no longer young, and who have used large quantities of tobacco for many years. It is proportionately worse in those who, in addition, drink heavily, but some authorities hold that the tobacco, even in these cases, is solely to blame, and actually maintain that alcohol is antagonistic in effect to tobacco. This contention would appear to be somewhat difficult to substantiate, the general opinion being that in cases of tobacco amblyopia those are the *worst* where alcohol has also been used in excess. The disease generally comes on concurrently with failure of bodily strength, and may occur as age advances, or after any excess of debility. A frequent cause of such debility is, of course, the use of alcohol.

With failing strength an increase of tobacco may induce an amblyopia, or even the use of a quantity which, in health, had no apparent effect. If the case comes under early observation, and complete abstinence follows, the cure may be expected, under suitable treatment. Otherwise, the outlook is decidedly bad, and no improvement will occur if the use is continued, so that absolute abstention from tobacco is essential. Medical treatment should be obtained, and every care should be taken for improving the general health. The recognition of this condition is accomplished by noting the history of the case, which is generally one of reduced and variable vision of a more or less misty character, and in which spectacles give no decided improvement. Deficiency of central vision for the colours red and green, in addition to the foregoing symptoms, may be regarded as diagnostic. Careful enquiry from the patient, as to his habits, will generally decide the nature of the case.

Quinine amblyopia is another form of blunted sight, caused by taking quinine in large doses. Other alkaloids, prepared likewise from Cinchona bark, have been known to cause similar symptoms. In India and other tropical parts of the world large doses of quinine are frequently taken as a remedy for, and preventative of, ague and other diseases. Residents in such countries, who habitually dose themselves with the drug, are therefore particularly liable to have quinine amblyopia. The symptoms of poisoning from overdoses are deafness, singing in the ears, headache, failure of sight, and, in bad cases, absolute blindness, which frequently comes on suddenly, and may continue for several weeks. Both eyes are always affected, and usually the pupils are widely dilated. Generally some vision returns, with a more or less complete colour-blindness. The treatment is entirely medical, the cure being slow, and more or less imperfect, but no case of permanent blindness has been authenticated. Small doses of quinine, taken long after such an attack, have been known to induce a return of the trouble.

Acetanilide has been known to cause a temporary blindness, probably through its action upon the heart, while gelsemium may cause paralysis of certain of the ocular muscles with consequent diplopia and ptosis (drooping of the upper lid). Indian hemp (Cannabis Indica) causes peculiar visual hallucinations and delirium, while santonin frequently causes coloured vision, violet at first, which is succeeded by green, or yellowish green, after a time.

Salicylic acid and the salicylates may, when taken in large doses, cause a form of toxic amblyopia which is very similar to that caused by large doses of quinine. As all these drugs are in daily use, it is well when complaints are made of any of the foregoing symptoms that some little enquiry should be made as to whether any doctor's medicines in use may be the cause of the trouble. It is by no means uncommon for the optician to have such cases under his notice.

Lead poisoning from contaminated water supply, and from the handling of lead in either its metallic form, or as paint, is not uncommon. Effects of this poison in the system are retinitis, optic neuritis (possibly ending in atrophy), or more frequently amblyopia, either transient or chronic. There is often very marked impairment of vision, which may end in complete blindness, and usually both eyes are equally affected, though one may be worse than the other. When the fundus is examined by the ophthalmoscope a considerable shrivelling of the retinal arteries is observed, and this, in conjunction with other bodily symptoms, is taken as conclusive evidence that the diagnosis is accurate. The chief difficulty in making the diagnosis is to distinguish between the retinitis of lead poisoning and that of albuminuria. People whose employment is of such a character as to necessitate the handling of lead or its compounds are particularly prone to become victims. Amongst these may be mentioned lead founders, white lead makers, painters and decorators, plumbers and glaziers. Sundry other articles used in the arts and crafts have likewise more or less injurious effects upon vision; amongst these may be instanced benzol and carbon bisulphide, liquids which are largely used as solvents for india rubber and gutta percha, and in works where these materials are used there is a more or less constant permeation of the atmosphere with their vapours. Workers in such an atmosphere may develop an amblyopia very similar to that of the tobacco smoker. An entire avoidance of the fumes is necessary, accompanied by proper medical treatment.

Nitro benzol is a chemical product employed in the manufacture of certain perfumes, flavouring agents, and explosives. It causes toxic amblyopia in those workers who are exposed to its vapour. One of the symptoms of this form of poisoning is a marked dilatation of the pupils, with contraction of the fields of vision, wherein it *differs* from the amblyopia of the tobacco smoker. Inspection of the fundus by the ophthalmoscope shows the retinal veins to be darker than usual, engorged, and sinuous. Avoidance of the fumes, with tonics and good nutrition is correct treatment.

Summary :—

(*a*) Amblyopia is a defective condition of sight not correctible by the mere fitting of lenses. Medical investigation and treatment are more necessary than glasses.

(*b*) Amblyopia may be caused by some form of poisoning, e.g., from drink, tobacco, drugs, etc.

(*c*) *Large doses of Quinine* may produce complete blindness. Anglo-Indians, and residents in tropical countries, are often affected by overdoses of this drug.

CHAPTER XVIII.

CYCLOPLEGICS, MYDRIATICS, MYOTICS.

WHILST it is desirable that opticians should possess some knowledge of the effects of drugs upon the eyes, in order that they may be able to understand the consequences which arise from their use, and also be able intelligently to converse with clients or doctors upon these matters, it is entirely outside their province to apply drugs, either for purposes of examination, or estimation of refraction ; in fact, for any purpose whatsoever. Meddling with eyes of clients in this way must not be attempted under any circumstances. *Qualified medical men are the only proper persons to employ drugs* for the various purposes required in connection with the treatment of ocular diseases and optical defects. Drugs employed as cycloplegics, mydriatics, and myotics are strongly poisonous substances of high power. The agents generally used are vegetable alkaloids of complex character, extracted by chemical processes from various plants. They are chiefly used in the form of drops, ointments, or discs of gelatine impregnated with the required substance, and are classified by their effects.

Cycloplegics are the agents used to produce artificial paralysis of the ciliary muscle.

Mydriatics to produce dilatation of the pupil.

Myotics to contract the pupil, to excite accommodation, and to produce artificial spasm of the ciliary muscle.

It will be observed that cycloplegics and mydriatics are allied in their effects to a considerable extent ; but that myotics are diametrically opposite. It should be noticed that the effects produced are in all cases of a temporary nature.

For merely enlarging or dilating the pupil of an eye, so as to obtain opportunity to more fully examine the condition of the media or fundus, a mydriatic alone would be sufficient ; whereas, if it were necessary to completely suspend the action of the ciliary muscle, for the full estimation of refraction, it would be requisite to employ a cycloplegic.

Some agents are rapid mydriatics and yet are *not* powerful cycloplegics, but on the other hand, most of the cycloplegics are also very powerful mydriatics. Below are tabulated the commoner substances employed for these purposes, together with the strengths of the preparations used. Subsequently we will consider the method of application, because it is desirable that opticians should be able to answer correctly the enquiries of their customers upon these and kindred matters connected with the medical treatment of the eyes.

CYCLOPLEGICS.	MYDRIATICS.	MYOTICS.
Atropine 1%, or less.	Atropine ·0005%	Eserine 0·25%
Homatropine 1%	Cocaine 1% to 2½%	Pilocarpine 0·25%
do. with Cocaine 2½%, or less.		(or stronger).

Other drugs are also employed, but the above are the most usual and best known. Having been in use for many years their effects, uses, properties, and dangers are thoroughly well understood.

Drugs occasionally employed as mydriatics and cycloplegics are daturin, duboisine, hyoscyamine, euphthalmine, scopolamine, etc. All these vary more or less in their effects, according to their several natures. The oldest, most usual and probably the best all round mydriatic is atropine. It is prepared from the plant known as belladonna (deadly nightshade), and is intensely poisonous. The strength of the official solution of the Pharmacopœia is 1 %, one grain of atropine sulphate being contained in 110 minims of the solution. It will be noticed that the drug employed is not pure atropine, but a compound known as sulphate of atropine. This is much more readily soluble.

This solution is, however, by no means always used of the strength indicated in the pharmacopœia. It is generally employed very much weaker. For children, who are frequently subjected to a prolonged atropinisation, for the purpose of breaking down a condition of spasm of accommodation, or for dealing with a convergent squint, it is usually made very considerably weaker. It is also used in extremely weak solutions, 1 in 5000, to 1 in 2000, in cases of incomplete nuclear cataract, to enlarge the pupil, and expose an area of lens unobscured by opacity, thus frequently giving better vision than is possible with a normal sized pupil. Atropine does not cause the same enlargement of the pupil in old age as in youth. It is said to lower the tension of healthy eyes, but if they are glaucomatous it increases their tension.

Apart from its use as an aid to the oculist in refractional work atropine is frequently used for its physiological effects upon the eyes. For example, in cases of adhesion of the iris to the lens or cornea, atropine is used to drag it away, by causing forcible dilatation of the pupil ; in asthenopia, photophobia, iritis, and corneal ulceration, it is an ocular sedative, and rests the accommodative system of the eyes. It seems to greatly lessen the photophobia always present in the two last named. Similarly, it is used in some affections of the conjunctiva. In cases of malignant myopia it is a valuable ocular sedative. Summarizing, we see that atropine is employed chiefly for :—

1. Relaxing spasm of accommodation.
2. Preventing accommodation in cases of squint.
3. Myopia, where rest of the eyes is needed.
4. Enlarging the pupil in senile cataract.
5. Affections of conjunctiva, cornea, choroid, iris and retina.
6. Paralyzing accommodation, prior to testing refraction.

With persons over forty years of age it is seldom necessary for the last purpose. When atropine is used for adults, it should be as strong as for children. It is generally believed that the ciliary muscle does not suffer any appreciable loss of power until extreme old age. Failure of accommodative power with advancing years is believed to be due to loss of elasticity in the crystalline lens rather than to failing ciliary strength. It is occasionally positively dangerous to use atropine for old or middle aged persons, as it has been known to initiate a glaucomatous condition, and in other cases to produce, in persons of certain temperaments, marked symptoms of *belladonna poisoning*. This latter may also occur at any age, through careless instillation, or morbid personal susceptibility. The commoner symptoms of poisoning from the use of atropine are dizziness, unsteadiness of gait, rambling delirium, dryness of the throat, redness of the face, vomiting, diarrhœa, irregular and quick pulse, and in extreme cases—death. Conjunctivitis is a frequent consequence. It is, however, of temporary character, and merely due to local congestion from the use of the drug.

Atropine should *very rarely* be used for persons over forty years of age ; *never*, when in any case there is a suspicion of glaucoma, and *never* for women who are nursing children.

METHOD OF INSTILLING ATROPINE.

If a solution is employed, an ordinary glass dropping tube, fitted with India rubber ball, and in appearance precisely like the fillers used for charging fountain pens with ink, will be found the most convenient, as well as the simplest instrument to employ. The "dropper," as it is termed, should be scrupulously clean, and should not be used for any other purpose whatsoever. The tube is filled from the bottle containing the solution by its own power of suction. Then, by carefully pressing the rubber ball the fluid can be discharged drop by drop, as desired, after a very little practice. It is well for the user to first gain proficiency by experimentally using the tube with a little pure water. The patient's head is usually tipped slightly backwards, and he is told to look upwards steadily. The lower lid is then drawn down by the operator's left forefinger, and into the lower conjunctival sac, as near as possible to the outer canthus, one drop of the atropine solution from the tube is allowed to flow. The lower lid is immediately released, and the eye allowed to close. If desired, the solution may be made slightly warm. The tip of the dropper should not touch the patient, for fear of a possible pollution. The patient is instructed to keep the eye quietly closed for a few moments, and to press the tip of his first finger against the inner canthus of the eye, so as to prevent the passage of atropine into the nasal duct, and thence into the throat. The cheek should be lightly wiped with a soft handkerchief to prevent any wasted or over-flowing solution from running down the face into the mouth. This is an accident which might easily happen during the instillation of atropine into the eyes of unruly or crying children. Instead of pressing the finger upon the inner canthus, to prevent passage of atropine into the nose, some authors suggest a gentle *traction* on the inner canthus in a downward direction, so as to remove the punctum from contact with the globe, and prevent it imbibing the solution by suction.

Another method of instilling atropine is to tell the patient to look fixedly downwards, and whilst he is so doing the operator raises the patient's upper eyelid, and gently *places* upon the sclerotic, on its upper and outer portion, one drop of solution from the tube. This should be *placed* upon the eye, and not suddenly "dropped" from the tube, so as to avoid causing the patient any shock, which might cause him to jerk his head, and so possibly produce an accident. The upper lid is held open for a minute or so, until the fluid has diffused itself over the front of the globe, and the patient has sufficiently recovered from the instillation to be able to keep the eye open naturally without difficulty.

Atropine, thus instilled, begins to take effect very quickly, dilatation of the pupil occurring in fifteen minutes, and complete paralysis of accommodation after two hours. The effect remains at a maximum for about 24 hours, and then gradually diminishes, but the entire effect does not usually pass away for several days, in some cases even for a week or more. Solutions of sulphate of atropine will keep good for a long time. The quantity instilled is usually one drop in each eye, two or three times a day. Atropine exerts a more prolonged effect than other cycloplegics, and if continuous suppression of accommodation is required, is undoubtedly the best drug to employ. When instilled by the patients or their friends it is often unskilfully done, and owing to this, and consequent waste, it may be only partially efficacious. Patients using atropine should always be carefully instructed by the medical man how to properly apply it, and what its effects are likely to be. Many people are greatly alarmed and much misunderstanding and loss of confidence is frequently developed by the lack of timely warning before use. In bright weather it is often advisable for atropinized persons to use dark glasses. Patients should especially be warned about the impossibility of doing fine close work whilst under the influence of the drops, unless glasses are temporarily adapted for the purpose. The dangers of street traffic to those who have recently had atropine instilled is considerable. Patients leaving a hospital or surgery immediately after its instillation should always be accompanied by a friend. The disturbance and confusion of vision, which result after its use, render them especially liable to accidents. If symptoms of poisoning are observed the patient should at once seek the advice of the doctor prescribing the drops. In the meantime it is advisable to cease using them, to apply cold water bandages over the eyes, and to take cooling drinks. Some authors advise the internal administration of paregoric, in proper doses, as a safe and useful antidote.

Homatropine. Homatropine is considered to be the best of all cycloplegics for examination purposes. It produces its maximum effect in about one hour. Two hours later the effects begin to pass away, and recovery is complete in about 48 hours. The instillation of homatropine is usually conducted by the doctor immediately before an examination, and it is seldom prescribed for patients' own instillation. The usual strength of the solution employed is four grains to the ounce. In many cases it is combined with cocaine, which seems to increase the effect, and to yield a more satisfactory preparation. Several drops are consecutively instilled at intervals of 15 or 20 minutes. An hour or so after the first instillation the eye is ready for examination. Homatropine is the most convenient of all cycloplegics to use when the patient's time and convenience have to be considered. Some authorities do not consider it strong enough for very young persons, where a complete cycloplegia is desirable. It is, however, capable of being used with complete success when persons are over 20 years of age. Homatropine is very expensive, and its effects are much more evanescent than those of atropine; moreover, the ciliary muscle is never so fully relaxed.

Glasses fitted under atropine or other powerful cycloplegic may not be quite right when the muscle recovers its natural tone. An allowance is generally made which varies with the nature, character and amount of the defect, also with the age and employment of the patient, and so forth. Plus lenses are made correspondingly weaker, and minus lenses stronger. The allowance, even in astigmatic cases, is always of spherical character. An empirical allowance often made is 1.00 D. in the cases of plus lenses, and 0.50 D. in the cases of minus lenses, in ordinary amounts of defect. Each case, however, requires individual consideration, and no rule can be given which will apply equally to all. (See Tables at end).

The chief myotics are *Eserine* and *Pilocarpine*. The former is more generally used. On the pupil its effect lasts for several days, but on accommodation only for a few hours. It is used to counteract cycloplegics and curtail the duration of their action. In glaucoma it is used to cause contraction of the pupil, and indirectly to reduce ocular tension, also in some affections of the cornea and peripheral corneal injuries, and after operations for cataract, to contract the pupil. Its instillation is often the cause of considerable acute pain, which, however, is not usually of long duration. Pilocarpine is a strong myotic, though considerably less powerful than eserine. It is considered less likely to produce iritis, and other undesirable complications.

Cocaine, which in itself is an admirable mydriatic, and useful whenever merely a rapid dilatation of the pupil is required, is a most powerful agent for producing anæsthesia (insensibility to pain), in almost all operations upon the eye. It acts by benumbing the nerve centres, and attains its maximum effect in about five minutes, although the pupil remains dilated for twenty-four hours or more. The solutions used vary in strength from 2% to 10%.

All the drugs previously mentioned may be applied to the eyes in the form of thin discs of gelatine, instead of drops. These are placed in the lower conjunctival sac, by means of a small camel hair pencil, and the lids closed for a few minutes until solution is affected. Alkaloidal solutions in oils, and in vaseline, also variously prepared ointments, have been used, but are usually regarded at the present day as of secondary value.

Belladonna and hyoscyamus, when taken medicinally, may in certain cases cause temporary mydriasis and loss of accommodation. *Narcotic drugs*, such as opium, morphia, chloral, and cocaine, have usually well marked effects upon the action of the pupils, though not much is recorded as to their effects upon vision. Opium and morphia cause great pupillary contraction. Chloral causes contraction of the pupils during stupor and sleep which it induces, but on waking the pupils dilate widely. Cocaine causes dilatation. Numerous other drugs used in medicine have marked effects upon the eyes ; some of these were referred to in Chapter XVII.

Summary :—

(*a*) Mydriatics are pupillary dilators, but usually have *some* concurrent effect on accommodation.

(*b*) Cycloplegics paralyse accommodation, and at the same time produce mydriasis.

(*c*) Myotics cause contraction of the pupil, and excite accommodation.

(*d*) The agents employed for these purposes are all very powerful poisons, *and their use is confined to qualified medical men.*

(*e*) Patients should be warned what effects to expect, and instructed in the method of instillation of the drops, etc.

(*f*) Mydriatics are used in refraction work to facilitate inspection of the media and fundus, by dilating the pupil ; and cycloplegics to suspend accommodation, so that the condition of the refraction may be correctly estimated.

(*g*) There are many dangers connected with the use of mydriatics, etc., and considerable limitations to their employment, brought about both by age and personal idiosyncrasy.

Section III.

Vision and Lenses.

CHAPTER XIX.

OCULAR REFRACTION.

ALTHOUGH the human eye is a compound system, it may with advantage be studied as a simple refracting system, having one surface separating its assumed single medium from air, when it is known as a "reduced" eye, so that we may liken it to a block of glass with a curved end, and may investigate the effect of refraction at a single curved surface by reference to Figs. 57 and 58, the first of which shows a surface of separation between two media of refractive indices n_0 and n_2, the former being to the left and the latter to the right.

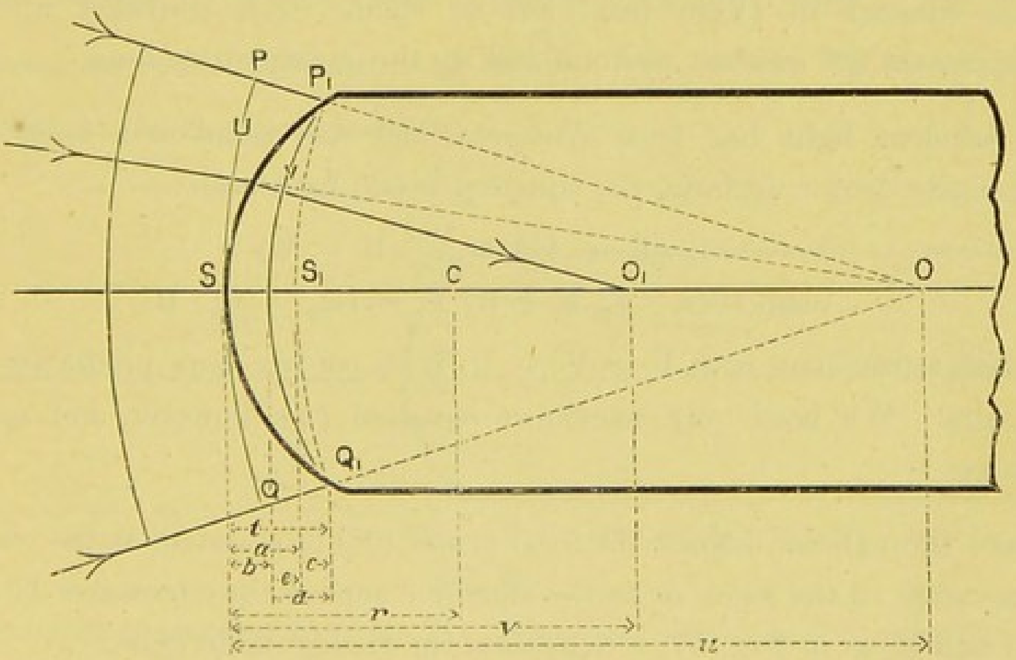


Fig 57.

An incident wave is converging towards O, and, passing from a medium of low into one of high refractive index, the paths of this wave will be bent towards the normal. One path is shown as proceeding to O_1, and OS is then the first conjugate distance u, O_1S being the second conjugate distance v. By the time the limits of the incident wave U reach P and Q the centre portion S is just coming under the influence of the more highly refracting medium, and by the time P reaches the surface at P_1, and Q at Q_1, S, instead of reaching S_1 will only have travelled a distance equal to b, owing to the retardation due to the medium of higher refractive index. We may say, therefore, that light would have travelled a distance a, but only travels over b in the given time.

$$\text{So that } \frac{a}{b} = \frac{V_0}{V_2} \left(\text{but } \frac{V_0}{V_2} = \frac{n_2}{n_0} \right)$$

$$\therefore \quad \frac{a}{b} = \frac{n_2}{n_0}$$

$$\text{or} \quad n_0 a = n_2 b$$

$$\text{or} \quad n_0 (t - c) = n_2 (t - d)$$

But curvatures are proportional to their sags standing upon the same chord.*

$$\therefore \quad n_0 (R - U) = n_2 (R - V)$$

$$\text{or} \quad n_2 V - n_0 U = (n_2 - n_0) R \qquad (1)$$

This equation holds under all conditions if the rules laid down in Chapter I. are adhered to (light from left to right, etc.), provided n_0 *always* represents the incident medium and n_2 the emergent medium.

If the incident light had been *divergent*, and still came to a focus in the optically denser medium, the equation would have been :—

$$n_0 (R + U) = n_2 (R - V)$$

$$\text{and then} \quad n_2 V + n_0 U = (n_2 - n_0) R.$$

which harmonizes with F = V + U, for a convex lens producing a real image. We need only remember equation (1), however, and apply the rules.

We have throughout defined the focal power (F) of a system as the change in curvature of the wave, or as the algebraic sum of the curvatures U and V, so that if, as in Fig. 57, e represents the change undergone :

$$e = d - c \quad \text{or} \quad F = V - U,$$

which again is in accordance with our notation, for this is the relation for *convergent* incident light upon a convex lens.

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* This is not absolutely correct, because the curvature is only proportional to the sag when either the curvature or aperture is small.

When the incident wave is plane (Fig. 58), we have F = V, because U = 0, and calling the incident medium n_0, and the emergent medium n_2, we may write down once for all the simple relation :—

$$n_2 \text{ F} = (n_2 - n_0) \text{ R}$$

$$\text{or} \quad \text{F} = \left(\frac{n_2 - n_0}{n_2}\right) \text{R} \qquad (2)$$

It will be obvious from this equation that the value of F depends upon which way light is passing, for since n_2 always represents the emergent medium it may stand either for the higher or lower refractive index.

Or again, in Fig. 58, let us consider a plane wave U incident (in air) upon R, and refracted so as to converge to O_1, then SO_1 will be the focal length measured *in the glass*. Similarly, if U_1 is a plane wave incident in glass (think of the diagram turned round, so that light still passes from L to R), then SO_2 is the focal length *in the air*, and $\frac{SO_1}{SO_2}$ must equal $\frac{n_0}{n_2}$, because from *glass to air*, when the incident wave meets the surface at P, this portion will have its speed accelerated, and the gain over the central portion Q is the time taken by Q to reach S, plus the rate of increase in speed, because during that time it will be travelling faster. The rate of increase in speed is determined by $\frac{V_2}{V_0}$ or $\frac{n_0}{n_2}$, where V_2 represents the velocity in the emergent medium.

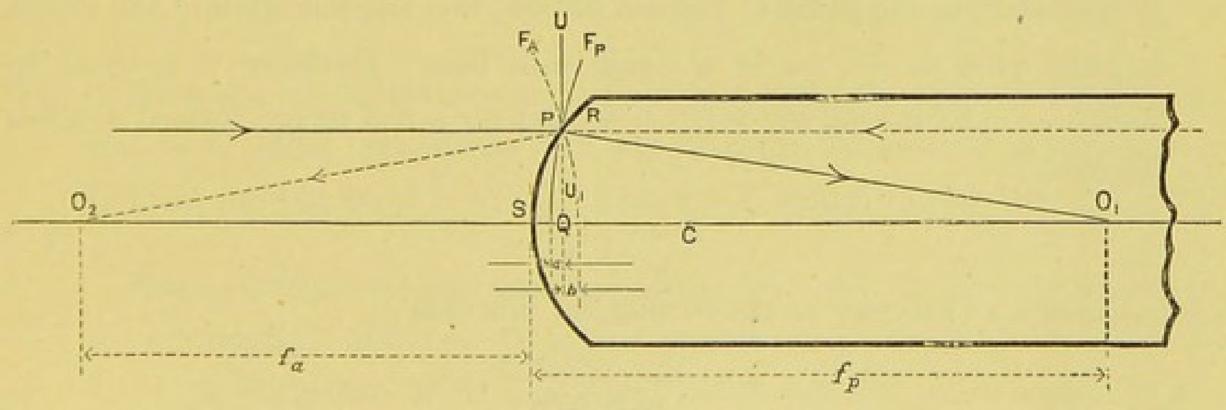


Fig. 58.

It will be found convenient to term SO_1 (the focal length in the optically denser medium) the *posterior focal length* (f_P), and SO_2, the focal length in the optically rarer medium, the *anterior focal length* (f_A). Hence we may write,

$$\frac{b}{a} = \frac{F_A}{F_P} = \frac{f_P}{f_A} = \frac{n_2}{n_0} \text{ (optically rare to dense medium).} \qquad (3)$$

$$\frac{b}{a} = \frac{F_A}{F_P} = \frac{f_P}{f_A} = \frac{n_0}{n_2} \text{ (optically dense to rare medium),} \qquad (4)$$

which, from air to glass, means that the posterior focal length is equal to the anterior focal length multiplied by the index of refraction of the glass, because air is unity.

From equation (2) it follows that

$$\frac{F_A \, F_P}{F_A - F_P} = R \qquad (5)$$

$$\text{or} \quad f_P - f_A = r.$$

So that the difference between the posterior and anterior focal lengths gives the radius of curvature of the surface.

Also from equations (1) and (2) we have

$$n_2 \, F = n_2 \, V - n_0 \, U$$

$$\text{or} \quad F = \frac{n_2 \, V - n_0 \, U}{n_2}. \qquad (6)$$

Which tells us that from air to glass ($n_2 = 1 \cdot 5$) the focal power determined will be F_P, whereas from glass to air ($n_2 = 1 \cdot 0$) the focal power determined will be F_A, n_2 *always* being the emergent medium.

From our previous definition of the optical centre it follows that for a single surface it is always coincident with the centre of curvature, C, in the figures. And since an object point and its corresponding image are joined by a secondary axis through this point, it follows that if u and v are measured from the point C (optical centre) the magnification of the image is given by $m = \frac{v}{u}$, as for a single thin lens. However, it is usual to measure u and v from the surface, so that for a real image formed in glass we have :—

$$m = \frac{v - r}{u + r} \qquad (7)$$

From equation (1) it may be shown that for this case

$$r = \frac{(n_2 - n_0) \, u \, v}{n_2 \, u + n_0 \, v},$$

and by substituting these values in the above equation we find that

$$m = \frac{n_0 \, v}{n_2 \, u} = \frac{n_0 \, U}{n_2 \, V} \qquad (8)$$

This equation holds under all circumstances providing u and v are measured from the vertex of the surface.

The following examples will illustrate the practical application of the preceding equations.

Example (1). To determine the anterior and posterior focal lengths of Donders' *reduced* eye (See Chap. XXI.) We have given :

Radius of curvature ... ... = 5 mm.
Refractive index of air ... ... = 1·0
Refractive index of the medium of the eye = 1·333

Since $r = 5$ mm.

$$R = \frac{1000}{5} = 200 \text{ dioptres.}$$

To determine f_P (air to eye) we have from equation (2)

$$F_P = \left(\frac{1·333 - 1·0}{1·333}\right) 200$$

$$= 50 \text{ dioptres}$$

$$\therefore \quad f_P = \frac{1000}{50} = \textit{20 mm.}$$

To determine f (eye to air, the eye being on the left)

$$F_A = \left(\frac{1·0 - 1·333}{1·0}\right) (-200)$$

$$= 66·6 \text{ dioptres}$$

$$\therefore \quad f_A = \frac{1000}{66·6} = \textit{15 mm.}$$

The result is positive in both cases, indicating a measurement to the right, and this is in strict agreement with our notation, for we have always to treat light as passing from L to R. Also $f_P - f_A$ equals r, and $f_P = f_A \times 1·333$.

Example (2). Given that an object (in air) is 10 cm. high, and situated 100 cm. from the surface of the glass block, which has a curvature of 10 dioptres, determine the size and position of the image.

We have given : Curvature of surface = 10D
Refractive index of air = 1·0
Refractive index of glass = 1·5
Size of object = 10 cm.
First conjugate distance $u = 100$ cm.

$$\therefore \quad U = 1 \text{ dioptre.}$$

We know that $n_2 V - n_0 U = (n_2 - n_0) R$ (Equation (1))

And also light is divergent ($-$ U)

Hence (1) becomes :— $n_2 V - (- n_0 U) = (n_2 - n_0) R$

$$\text{or} \quad n_2 V + n_0 U = (n_2 - n_0) R$$

$$\text{or} \quad V = \frac{(n_2 - n_0) R - n_0 U}{n_2}.$$

And it is air to glass, therefore $n_0 = 1$, and $n_2 = 1·5$.

$$\therefore V = \frac{(1·5 - 1·0)\,10 - 1\,(1·0)}{1·5}$$

$$= 2·66 \text{ dioptres.}$$

$$\therefore r = \frac{100}{2·66} = 37·5 \text{ cm.}$$

The image, therefore, is situated 37·5 cm. from the surface, and is a real inverted one formed in the glass block itself, since the *sign* is positive.

The size of the image, obtained with the aid of equation (8) is given by

$$10 \left(\frac{1·0 \times 37·5}{1·5 \times 100}\right)$$

$$= 2·5 \text{ cm.}$$

We may represent the refracting system of the eye by a single surface separating two media, air and water respectively, if we give to the radius of curvature of the surface the value of 5 mm. We have for air $n = 1·0$ and for water $n = 1·333$ (Donders' "reduced" eye). With these data we can obtain sufficiently accurate solutions to all practical problems relating to vision, some of which are dealt with in a subsequent chapter.

The difference between an *emmetropic* and an *ametropic* eye has already been referred to in previous chapters, and some idea has been given of the conditions known as hyperopia, myopia, astigmatism and presbyopia. The fact of the object seen and the retinal image being conjugate foci has also been specified as necessary for distinct vision, but it does not follow that an eye having distinct vision is emmetropic, for in Chap. XI. we have seen that the hyperope may in many cases overcome his defect by using accommodation for distant vision, the amount used being a measure of the defect, which is described as *latent*, or hidden, in opposition to a *manifest* error, such as would be seen were the eye under atropine. The normal or emmetropic eye, therefore, should have the average accommodation available for its particular age, in other words its near point should be normal in position.

Fig. 59 represents the two instances of a young emmetropic eye, having ample accommodative power, focussed (I.) for a distant object, and (II.) for a near object. Because the eye is young, even the very divergent waves

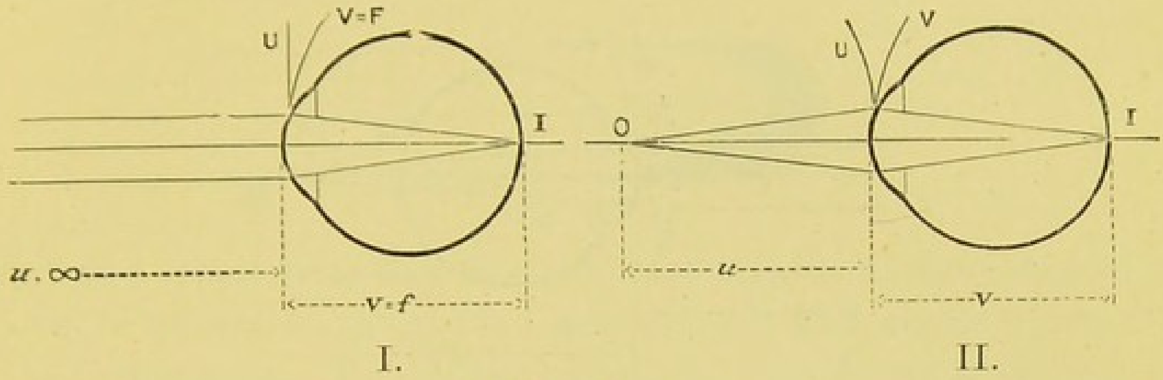


Fig. 59.

proceeding from O (in II.) are brought to a focus at I. upon the retina, and it is evident that the refracting power must be greater than in I., where F, the focal power, equals V, since U = 0 (plane wave), while in II. we have F = V + U, but V is the same in both instances so that the focal power in the second must be greater than in the first.

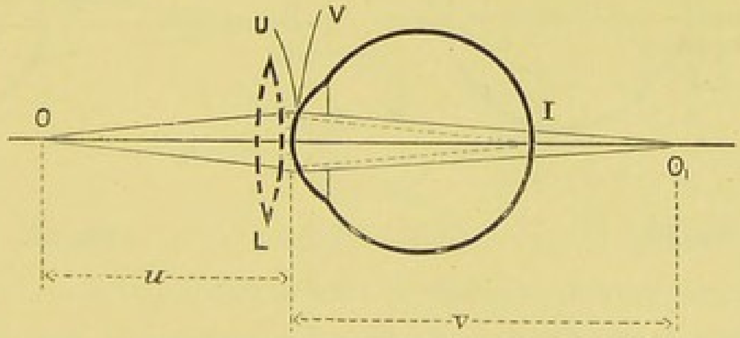


Fig. 60.

Now let us consider the case of an old emmetropic eye, in other words a normal presbyopic eye, Fig. 60. Plane waves of light are brought to a focus just as in Fig. 59 I., but the eye is now unable, *unaided*, to refract waves diverging from O sufficiently to focus them upon the retina, and they would meet at O_1, a disc of light instead of a point being formed at I. Thus, waves diverging from so near a point as O cannot be focussed upon the retina at all, because of the loss of accommodation through age, and a suitable convex lens L must be placed in front of the eye to supply the deficiency.

In Fig. 61 a young hyperopic eye is indicated, which, by reason of a deficiency in its refracting system, cannot focus parallel light upon the retina, the point focus being at O_1. By employing accommodation this may be remedied,

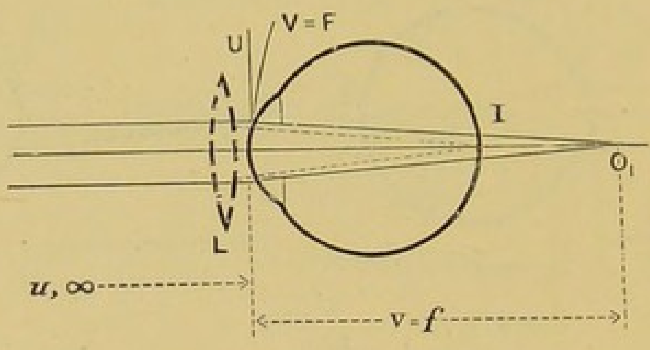


Fig. 61.

but it may then have insufficient remaining for viewing near objects, and it is better to correct the error by placing a lens L in front of the eye, thus removing the latent defect.

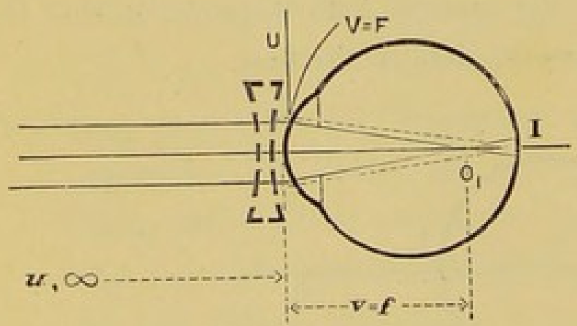


Fig. 62. I.

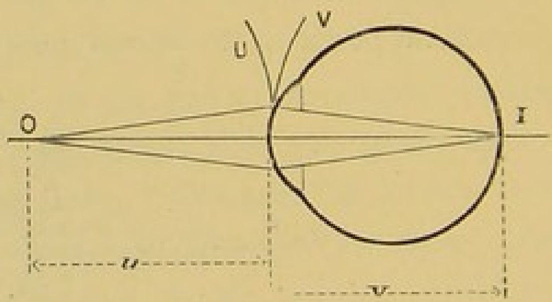


Fig. 62. II.

Fig. 62 illustrates a myopic eye, in which the refracting system is too strong to focus parallel light upon the retina, the point focus being at O_1, and a negative or concave lens must be placed in front of the eye in order to weaken the power. But we have seen that light diverging from a near object requires a stronger refracting system to focus it upon the retina, and consequently there will be some particular point (O in II.) from which divergent light will focus exactly upon the retina, and this is known as the *far point* of such an eye, accommodation becoming necessary for any position inside O which can be viewed by its aid.

An Astigmatic Eye may be defined as one which possesses a toroidal surface or its equivalent. This may be defined as one having varying curvatures in different meridians, with a maximum and minimum curvature at right angles, *toroid* being the scientific name for a surface like that of a bicycle tyre. In Fig. 63 AB and CD represent the radii of curvature of the two chief meridians.

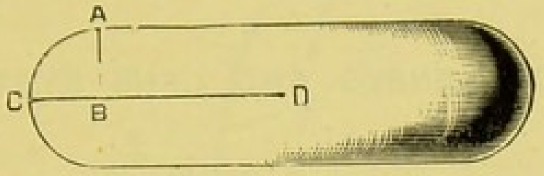


Fig. 63.

With such a surface separating two media of different refractive indices light will be brought to two line foci, separated one from another, instead of to a single point. The distance between the foci is known as the *interval of Stürm* (H to V in Fig. 64), and between these two foci a disc of light will be formed, known as the *circle of least confusion.* For convenience the meridian of least power may be termed the axis of the surface or lens.

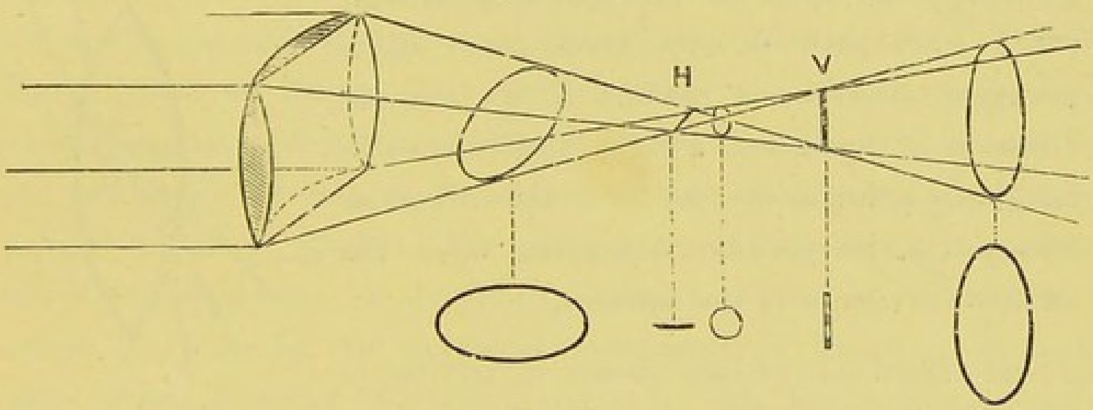


Fig. 64.

The equivalent *in effect* of a toroidal surface is a sphero-cylindrical lens (Fig. 64), a crossed cylindrical lens of unequal powers, or a tilted spherical lens. The error of refraction known as astigmatism is, therefore, capable of being corrected by one of these types of lenses, or by one having a toroidal surface, suitably placed before the eye.

Summary :—

(*a*) The human eye may be studied as a single refracting system, being then known as a "reduced" eye.

(*b*) $n_2 V - n_0 U = (n_2 - n_0) R$, when n_0 is the incident medium and n_2 the emergent medium.

(*c*) Consequently $F = \left(\frac{n_2 - n_0}{n_2}\right) R = \frac{n_2 V - n_0 U}{n_2}$

(*d*) A toroid, a sphero-cylinder, a crossed cylinder of unequal powers, and a tilted spherical lens may be equivalents.

CHAPTER XX.

THICK LENSES AND LENS SYSTEMS.

ALTHOUGH we can in practice treat the refracting system of the eye as consisting of a single spherical surface separating two media of different refractive indices, we must know the meaning and properties of what are called the *cardinal points*, because of the combined effect when corrective lenses are placed before the eye.

The optical centre of a single lens has been defined as that point upon the principal axis through which every path of light must pass whose emergent direction is parallel to its original direction of incidence, and it is still the same imaginary point in the case of a thick lens or lens-system, its position depending upon the relative curvatures of the surfaces.

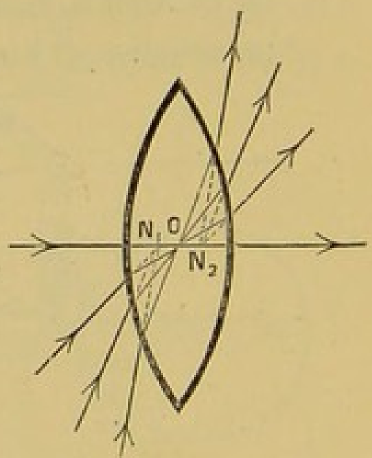


Fig. 65.

In the equi-curved convex lens shown in section in Fig. 65 the optical centre O will occupy a position midway between the two surfaces, for the emergent paths are all parallel to their respective incident paths, and therefore the conditions of our definiton are satisfied. Although in each case the emergent path is parallel to the incident path it is considerably *deflected* to one side, because of the extreme thickness of the lens, and consequently we cannot assume, as we did with thin lenses, that the images of the optical centre are coincident with it. Suppose a small air bubble to occupy the position of the imaginary optical centre, then an eye placed anywhere to the left of the lens would, apparently, see it at N_1, and if to the right of the lens at N_2. To an observer the points N_1 and N_2 are the collecting points for all paths of light emerging in a direction parallel to that of incidence. They are, apparently, the knots or *nodes* formed by such paths (rays) of light, and are therefore termed *nodal points*, being simply the images of the imaginary optical centre viewed through each surface of the lens respectively. But we must remember that the *secondary axes*, as paths of light having parallel emergence are termed, never actually pass through the nodal points, but through the optical centre.

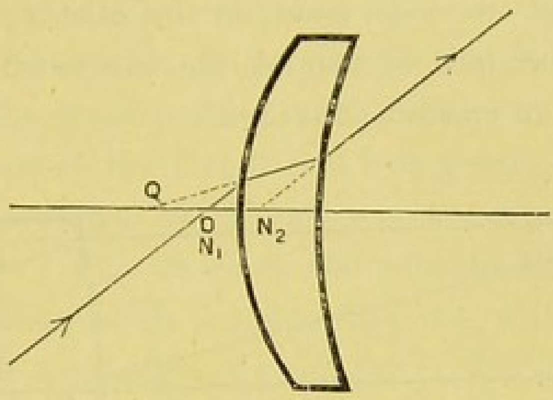


Fig. 66.

Fig. 66 represents a meniscus or periscopic lens, a single secondary axis being shown, the paths of incidence and emergence being parallel, and where the uniting path cuts the optic axis must lie the optical centre O. But as the nodal points are images of the optical centre, and this is outside the lens, it is evident that if it were a tangible object it would itself be seen by an eye placed to the left, so that there cannot be an image N_1 because no refraction takes place. We may however determine a position Q which will represent the position of the image (that is N_1) as seen from inside the lens, by the graphical construction of Fig. 24. In fact this point Q may be called the optical centre for thin lenses, being considered coincident with O, and various writers still so describe it, but as light must pass through the optical centre, and all secondary axes pass through O, which we *may* term N_1, it is clear that it is an error. The position of Q is e easily located, and it indicates the approximate positions of O (N_1) and N_2. This point does not vary in position with a change in refractive index, while O (N_1) and N_2 vary with the refractive index and curvatures of the two surfaces, and when the optical centre is on one surface or inside the lens Q is coincident with it. In future, when O is outside the lens or on one surface it will be referred to as the 1st or 2nd nodal point as the case may be.

Fig. 67 shows why all measurements should be made from the nodal points. A B being an object very remote from the lens, and the image *a b* therefore being in the focal plane, *b* coinciding with the focal point F. The position of *a* is determined by a secondary axis A N_1 N_2 *a* an path from A parallel with the optic axis, refracted by the lens at C, and on emergence again at G. If these incident and emergent paths are produced so as to intersect, they determine the position of one nodal plane, and consequently one nodal point, in this case N_2. The position of N_1 can also be determined by turning the lens round and passing a similar path through in an opposite direction.

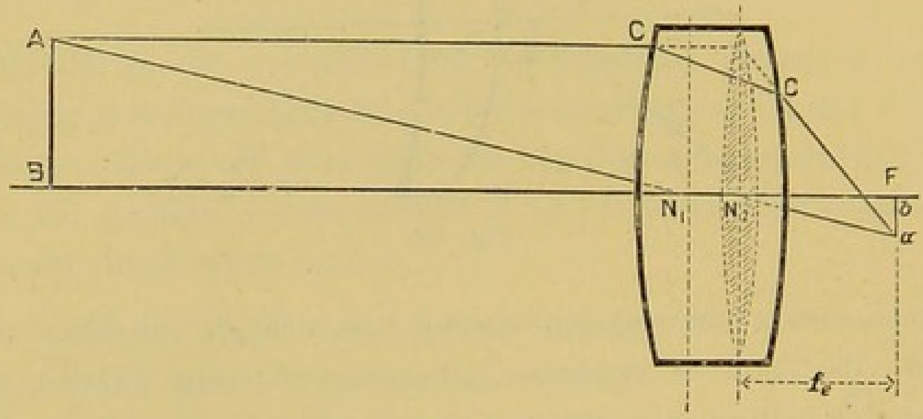


Fig. 67.

However much A C is refracted by the thick lens this work could be done by a single thin lens placed in the nodal plane of emergence, and shown in dotted outline. It is the equivalent lens, and its optical centre coincides with N_2. The same holds true for a compound system of lenses, even to determining N_1 by turning the system round, and in every case where the incident and emergent media have the same refractive index the anterior and posterior focal lengths f_A and f_P are equal (measured of course from the nodal points) since, if the lens were reversed, for light from A to be focused at a the point N_1 would have to occupy the present position of N_2. Thus if the lens had light passed through from right to left the equivalent thin lens would lie in the focal plane N_1, but as N_1 and N are not coincident the equivalent lens is not the exact equivalent. For it to be so we must imagine it by some means to suddenly move from one nodal plane to the other before the light has time to emerge from it.

As the triangles A B N_1 and $a\,b\,N_2$ are similar in all respects, the corresponding sides being parallel, we can measure conjugate distances u and v from N_1 and N_2 respectively, and so apply our simple lens equations for solving thick lens problems. Hence, for thick lenses or lens-systems in air,

$\mathrm{F} = \mathrm{V} - \mathrm{U}$ and $m = \dfrac{\mathrm{U}}{\mathrm{V}}$ as with thin lenses.

In practice the experimental determination of the positions of the nodal points is made by supporting the lens or lens-system in a V-shaped trough, which itself can be rotated on its support about a vertical axis. The image of an object should be received on a screen with cross-lines upon it. Experiment will show that by moving the lens or lens-system along the trough, keeping the image in focus, one position can be found in which no amount of rotation of the trough and lens system, about a vertical axis, will cause any movement of the image on the screen with respect to the cross-wires upon it. Fig. 68 shows that with the lens in such a position the axis of rotation which is the centre line of the support, must be coincident with the nodal plane of emergence. The position of the other nodal plane may be determined by turning the lens round, and making the present nodal point of incidence the nodal point of emergence. The distances N_1 and N_2 from the first and last lens surfaces respectively can be determined with considerable accuracy, for p, q, u, and v are all easily obtained, and the positions of the nodal planes upon the lens mount may be marked. If the object is at a considerable distance, v will equal f, the true equivalent focal length.

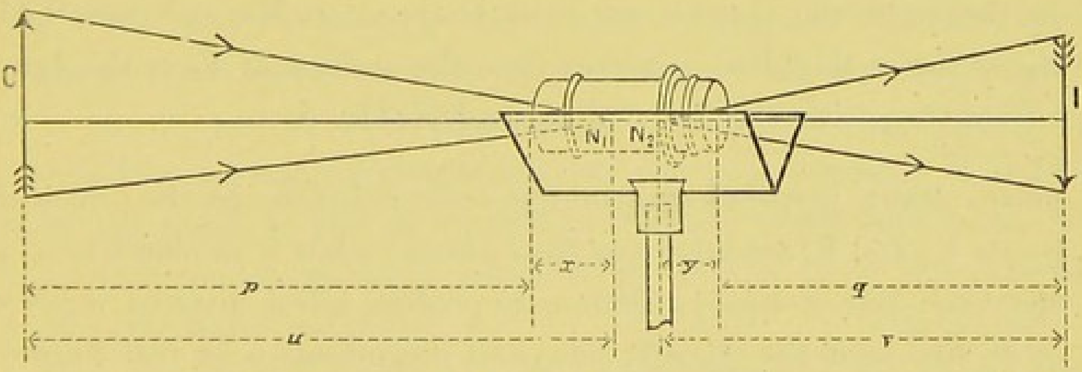


Fig. 68.

Gauss discovered that every optical system, however complex, acts as a simple thick lens ; and, therefore, as a simple thin lens placed in one nodal plane to receive the light and then rapidly shifted to the other nodal plane to emit it. He also deduced equations which enable us to determine the properties of any lens-system, however complex, dealing with it *as a whole*, instead of as a series of separate parts, and so that they may be applicable to all cases he laid down the condition that all conjugate distances must be measured from *planes of unit magnification*, called *principal planes*, which are not necessarily the nodal planes in all cases, as we shall see.

Fig. 69 illustrates *planes of unit magnification*, irrespective of what we shall afterwards call *symmetrical planes*. O is an object in the plane of the optical centre of a rectangular block of glass, and to an eye on the left it appears of the same size, but in the first nodal plane N_1. Similarly, rom the right it appears at N_2, and the incident and emergent paths of light, being parallel to each other, show the position of N_1 and N_2. If now we curve the surfaces of the block it becomes a lens, and although, if the object is large, the images may be distorted, unit magnification is preserved, so far as the secondary axes are concerned.

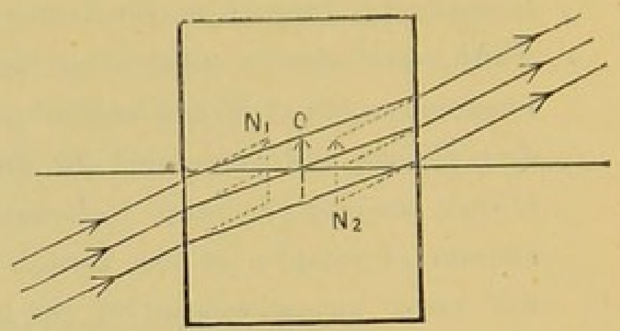


Fig. 69.

For any thick lens in air therefore, the nodal planes are identical with the principal planes of Gauss, and this applies also to all complex systems with the same surrounding medium. When single lenses are separated the nodal points of the system may overlap, so that in Fig. 68, to an eye on the right the optical centre *might* appear at N_1, and from the left at N_2, so that u might be measured from the position of N_2 in the figure and v from the position of N_1. (Chapter XXIII).

The planes drawn perpendicular to the optic axis through the principal focal points F_1 and F_2 are known as *focal planes*; while if an object be so placed upon one side of a lens system as to produce a real inverted image of the same size upon the opposite side (unit magnification for real image) then the positions of object and image are known as *symmetrical planes*, and the points where they cut the axis are symmetrical points.

There is one important thing to remember when we are dealing with thick lenses or separated thin lenses *in air*, viz., that the principal points of Gauss, called sometimes by others *equivalent points*, are coincident with the nodal points defined above.

If now we imagine a thick lens with air on one side and water on the other the effect upon light emergent in water will be to reduce the amount of bending, so that we shall have now an anterior and posterior focal length differing in value in the ratio of the refractive indices of air and water respectively, just as in the case of a single surface. And if f_A and f_P are the corresponding focal lengths in air and water, and n_0, n_4, the refractive indices for the incident and emergent media respectively, as in Chapter XIX,

Then $\frac{F_A}{F_P} = \frac{f_P}{f_A} = \frac{n_4}{n_0}$ (optically rare to dense medium)

and $\frac{F_A}{F_P} = \frac{f_P}{f_A} = \frac{n_0}{n_4}$ (optically dense to rare medium)

We have already stated that the focal lengths are measured from the principal planes, which must also be planes of unit magnification, and the effect of having water upon one side, with increase of equivalent focal length on that side, is to separate the principal planes from the nodal planes as seen

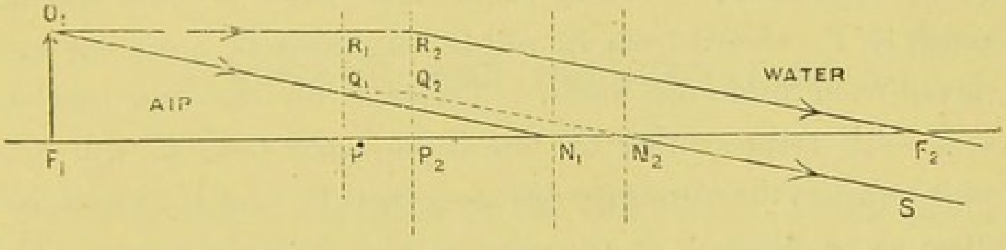


Fig. 70.

diagrammatically in Fig. 70, where P_1 P_2 are the principal points and N_1 N the nodal points of a system having water to the right, in which is the posterior focus F_2 and air to the left, in which is the anterior focus F_1. As P_1 and P_2 are in planes of unit magnification an object in P_1 viewed from air would appear of the same size as if it were in P_2 and viewed from the water, so that an equivalent thin lens would have to occupy the plane of P_1 and be suddenly moved to P_2 in order to do the work of the system, the water included.

What effect does the water have upon the optical centre? Let us imagine the system of lenses reduced to a single curve with water to the right. Then the optical centre will be at the centre of curvature, with the single nodal point, and the principal points will be united at the intersection of the principal axis with the curve. Thus as we increase the refractive index of the medium to the right so the optical centre, of which the nodal points are still images, is displaced to the right.

In Fig. 70 light from O_1 in the first focal plane emerges from the system as a parallel beam, and since O_1 N_1 and N S are parallel (forming a secondary axis) then P_1 $P_2 = N_1$ N_2. Also triangles N_1 O_1 F_1 and F_2 R_2 P_2 are equal in every respect so that F_1 $N_1 = P_2$ F_2, and as P_2 F_2 is the posterior focal length, F_1 N_1 is also. F_1 P_1 is the anterior focal length, so that the equal distances $P_1 N_1$ and $P_2 N_2$ are each given by the difference between the posterior and anterior focal lengths. As we have already stated, with air on both sides $f_A = f_P$, N_1 coincides with P_1 and N_2 with P_2.

Such a system as that represented is similar to what we find in the human eye, and we require to know the positions of P_1 P_2 in order to calculate conjugate distances, whereas when dealing with the size of the image (magnification) we have to take measurements from N_1 and N_2 so as to employ the relations existing between the "quantities" of similar triangles.

The equivalent thin lens, to do the work of the system, including the water, has to be placed in the plane P_1 to receive the light, and rapidly shifted to the plane P_2 to emit it. These planes are planes of unit magnification insomuch as P_1 viewed from air will be magnified to a similar extent as P_2 viewed from inside the water. Therefore for the thin lens equation $F = V - U$ (representing the law of conjugate foci) to still hold true we *must* measure the conjugate distances from P_1 and P_2, which, with such a system as represented, do not coincide with the nodal points. The nodal points, however, are still of some use, for when dealing with magnification we often find it convenient to measure v and u from the nodal points N_1 and N_2, so as to employ, as stated above, the relations existing between the "quantities" of similar triangles. So that even with such a complicated system we may still write

$$F = V - U \quad (u \text{ and } v \text{ from } P_1 \text{ and } P_2)$$

$$m = \frac{U}{V} \qquad (u \text{ and } v \text{ from } N_1 \text{ and } N_2) \quad \text{See page 146 } \frac{n_0 U}{n_2 V}$$

employing the same notation as has been adopted throughout the book.

Summary:—

(*a*) The nodal points are images of the optical centre.

(*b*) An equivalent thin lens may be found for any thick lens or lens system, if we assume it to move from one definite position to another with infinite rapidity.

(*c*) The principal planes are those of unit magnification, and from them u and v are measured.

(*d*) For lenses or lens systems in air N_1 and N_2 coincide with P_1 and P_2 respectively.

(*e*) These are separated when the media are different on the two sides of the lens or system.

(*f*) For "magnification" it is convenient and usual to measure u and v from N_1 and N_2.

CHAPTER XXI.

SCHEMATIC AND REDUCED EYES.

THE theory of Gauss, explained in the last chapter, affords us great help when applied to the eye, for the difficulty of calculating the exact course of light through so many media, with different refraction at the various surfaces, becomes apparent when we realize the complexity of the organ of vision. Working with the theory of Gauss we can find for the entire ocular refracting system an anterior focus, a posterior focus, two principal points and two nodal points. The question arises as to what eye we are going to take as a standard; evidently it must be emmetropic, neither too short nor too long in the bulb, nor may we have a cornea whose curvature is in any way abnormal. A model eye is needed, and many scientists at different times have given careful attention to measuring the various curvatures, and calculating the refractive indices of the media. The resulting figures give what are known as *the optical constants of the human eye*, and the model constructed to conform to these measurements is called a *schematic* (diagrammatic) *eye*. Listing was the first to construct such, and the schematic eye of Listing was named accordingly. He, too, introduced the idea of a *reduced* (simplified) *eye* for the purpose of obtaining results sufficiently accurate with a minimum amount of calculation. Helmholtz gave us figures which have been generally accepted as very accurate; and later, Tscherning, with the most recent appliances, has made more exact measurements in several respects. These we may tabulate as follows :—

	LISTING.	HELMHOLTZ.	TSCHERNING.
Refractive index (n) of cornea ...	—	1·3507	1·377
" " of aqueous / " " of vitreous	1·3376	1·3365	1·3365
Mean refractive index of lens ...	1·4545	1·4371	1·42
Radius of curvature of anterior surface of cornea	8 mm.	7·829 mm.	7·98 mm.
Ditto, posterior surface	—	—	6·22 mm.
Radius of anterior surface of lens (at rest)	10 mm.	10 mm.	10·2 mm.
Ditto, posterior surface	6 mm.	6 mm.	6·17 mm.
Distance from anterior of cornea to anterior of lens	4 mm.	3·6 mm.	3·54 mm.
Thickness of lens	4 mm.	3·6 mm.	4·06 mm.
Thickness of cornea	—	—	1·15 mm.

Here we have a complete set of measurements, from which we can calculate the value of the total ocular refraction. By the theory of Gauss the entire refracting system of the human eye may be represented by a single thin lens, having the property of moving with infinite rapidity from the principal plane of incidence to the principal plane of emergence. If then we know the positions of the various cardinal points we shall be in a position to draw to scale our schematic eye, from which we may deduce data for the reduced eye on the lines suggested by Listing. Below are the figures of Helmholtz and Tscherning for the various cardinal points.

	HELMHOLTZ.	TSCHERNING.	
Position of 1st. p.p. ...	1·75 mm.	1·54 mm.	measured from the anterior surface of the cornea.
" " 2nd. p.p. ...	2·11 mm.	1·86 mm.	
" " 1st. n.p. ...	6·95 mm.	7·30 mm.	
" " 2nd. n.p. ...	7·31 mm.	7·62 mm.	
" " anterior focus ...	13·73 mm.	15·59 mm.	In front of cornea.
" " posterior focus	22·79 mm.	24·75 mm.	Back of anterior cornea.

The positions of the nodal planes are given by the difference between the anterior and posterior focal lengths, thus, taking Helmholtz's figures :—

$$f_P - f_A = (22{\cdot}79 - 2{\cdot}11) - (13{\cdot}73 + 1{\cdot}75)$$
$$= 5{\cdot}20 \text{ mm.}$$

So that the first nodal point is 0·25 mm. to the anterior side of the posterior surface of the lens, and the second is 0·11 mm. to the posterior side of the same surface, the distance between them being the same as between P_1 and P_2. (0·36 mm.)

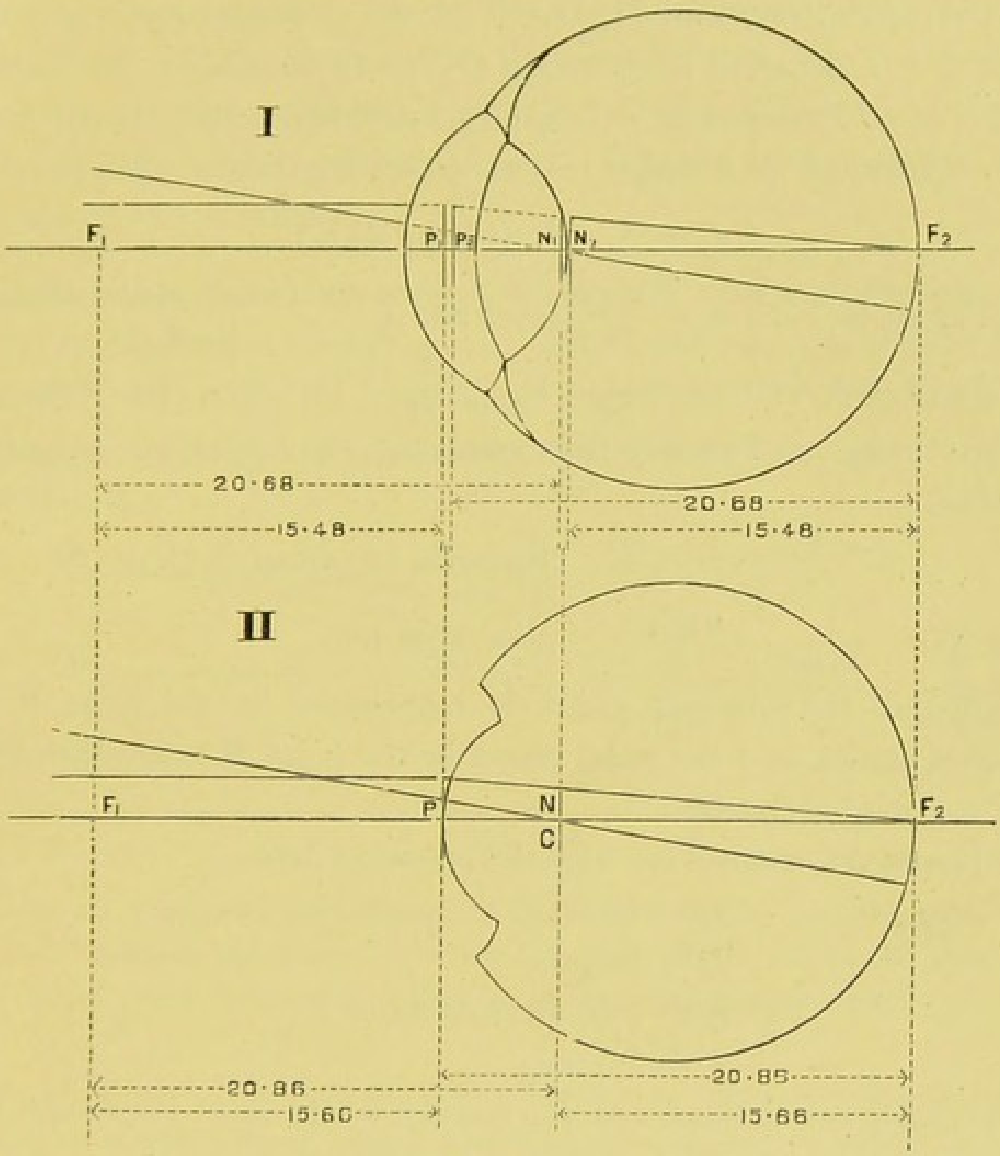


Fig. 71.

Fig. 71, I, gives us the schematic eye (distances twice "actual") after data supplied by Helmholtz. In this the two principal planes and two nodal planes almost coincide, and the principal planes are not very far from the cornea. A glance is sufficient to show that the entire refracting system of the human eye can, to a first approximation, be represented by a single surface separating two media having different refractive indices. In such a case the principal planes are coincident with the surface of separation, and nodal planes are coincident with the centre of curvature of the separating surface.

Listing proposed that the separation between F_1 and F_2, the anterior and posterior focal points respectively, should remain as for the schematic eye, and that refraction should be assumed to occur only at one surface, whose position should be taken as being midway between P_1 and P_2. Working on the schematic eye data (after Helmholtz) we have, therefore, for the reduced eye, Fig. 71, II,

Anterior focal length $(f_A) = 15{\cdot}66$ mm.

Posterior focal length $(f_P) = 20{\cdot}86$ mm.

Now, for refraction at a single surface separating two media

$$n_2 = n_0 \frac{f_P}{f_A} \text{ (Chap. XIX)}$$

$$\text{and as } n_0 = 1 \therefore n_2 = \frac{20{\cdot}86}{15{\cdot}66} = 1{\cdot}332 \left(\begin{matrix}\text{the refractive index of the}\\ \text{reduced eye.}\end{matrix}\right)$$

We also know that the reciprocal of $F_A = \frac{1}{f_A}$. Therefore, for light parallel within the eye, and passing from an optically denser to an optically rarer medium

$$\frac{1}{f_A} = \frac{n_2 - n_0}{n_2 \, r} \text{ (Equation (2) Chap. XIX.)}$$

$$\text{Therefore } \frac{1}{15{\cdot}66} = \frac{0{\cdot}332}{r} \quad \therefore r = 5{\cdot}20 \text{ mm.}$$

The position of the principal planes is represented by the point P on the adapted cornea, and the nodal planes by the point N coincident with the new centre of curvature C.

Donders proposed a *reduced eye* with the following data :—

$f_A = 15$ mm.

$f_P = 20$ mm.

$n_2 = 1{\cdot}3\dot{3}$ (that of water.)

$r \doteq 5{\cdot}0$ mm.

For rough calculations, and for making comparisons respecting the size of retinal images, etc., these data answer very well.

It is usual to reckon the positions of the various cardinal points from the anterior surface of the cornea, and this method of procedure is adopted in the following table which gives the results previously obtained in this chapter, together with results calculated from Tscherning's data in a like manner. All measurements are in mms.

	HELMHOLTZ (*Schematic*).	HELMHOLTZ (*Reduced*).	TSCHERNING (*Schematic*).	DONDERS (*Reduced*).
Position of anterior focus ...	13·73	15·66	15·59	15·0
,, posterior ,, ...	22·79	20·86	24·75	20·0
,, 1st P.P. ...	1·75	On cornea	1·54	On cornea
,, 2nd P.P. ...	2·11		1·86	
,, 1st N.P. ...	6·95	5·2	7·30	5·0
,, 2nd N.P. ...	7·31		7·62	

The anterior focus must not be confused with what is known as the "near point" in testing vision; it has quite a different signification, and, as previously explained, is the focus for light which, being parallel within the eye, converges after leaving the cornea and meets at this point, so that when the pinhole is placed at the anterior focus for the observation of entoptic phenomena light is actually parallel in the eye, diverging from the pinhole, and being parallel, casts shadows of obstructions within the media upon the retina.

The results obtained with the *reduced* eye, equally with those from the *schematic* eye, hold good for the actual eye. This being so, it is evident how much easier it is to study the formation of images on the retina by aid of the simplest optical system than with the very complex one of the normal human eye.

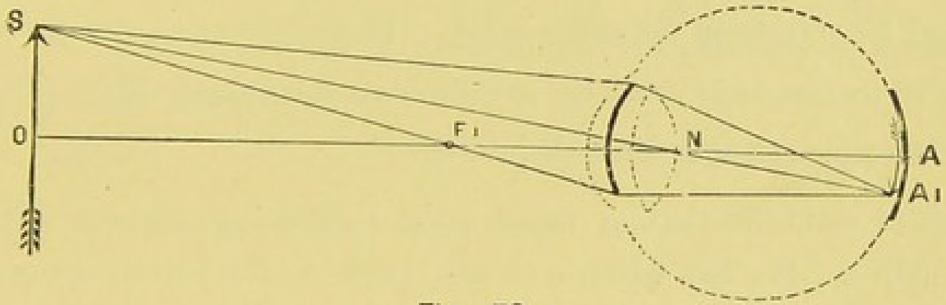


Fig. 72.

The normal eye is shown in the dotted outline, the "simplified" or "reduced schematic" eye being in dark lines. N is the single nodal point, O A the optic axis, F_1 the anterior principal focus.

In Fig. 72 is shown the formation of an image by the reduced eye, light from one extremity of an object passes along a secondary axis S A_1, through the nodal point, undergoing no refraction. Two other paths are shown, which are refracted at the "reduced" cornea and meet at A_1, which is the image of S, on the secondary axis. Every point in the object could be made to furnish an image in the same way, each having a path traversing an individual secondary axis, which must pass through the nodal point N, suffering no refraction, every other path being refracted at the imaginary cornea. Evidently, as the object approaches the anterior focus, the image moves further away from the nodal point, until with the object at the anterior focus light is parallel within the eye. A reference to Fig. 58 will make this evident.

It is instructive to note how the point F_1 might become a "near point" for testing. If we could increase n sufficiently to make the light parallel within the eye convergent, so as to meet at the retina, we should get an image. The crystalline lens would do this if the power of accommodation were great enough, but as we should require about 58 dioptres of available accommodation this is impossible ; in fact we should need a crystalline lens which could accommodate almost exactly the same number of dioptres as the total power of the eye.

We may summarize by saying that the refraction of the eye for parallel light incident in air and meeting the cornea is approximately 43D, but for light from the anterior focus it would require 58D of accommodation *extra* to form an image.

The magnitudes of image and object are proportionate to their distance from the nodal point of the reduced eye. Taking Donders' data the image is formed 15 mm. from the nodal point. If, therefore, we assume the object to be 15 metres away from the nodal point, the image will be $\left(\frac{15 \text{ metres}}{15 \text{ mm.}}\right)$, or 1000 times smaller than the object.

The results of some calculations based upon Tscherning's figures will be found instructive. He has given a certain value to the posterior surface of the cornea, and, so far as is known, no figures have previously been determined for this surface, a fact greatly adding to the interest of the following table.

Anterior surface of cornea	47·24 D	
Posterior „ „	−4·73 D	
Anterior surface of crystalline	6·13 D	Eye at rest.
Posterior „ „	9·53 D	

Adding these we obtain 58·17 D, which is, for all intents and purposes, the total refractive power of the eye. It is instructive to compare these figures with those obtained by the Helmholtz schematic and Donders reduced eyes. The approximation is very close.

From Tscherning's table we notice the remarkable power of the anterior corneal surface. The reason is obvious, when we remember that light entering the cornea comes from air, with $n = 1$, into a refracting substance whose $n = 1·377$. How different, when light passes from the aqueous humour, whose $n = 1·3365$, to the lens whose total n is only 1·42 ! In the former case the difference is nearly 0·4 while in the latter it is less than 0·1. Again, the actual curvature of the cornea is deeper than that of the anterior surface of the lens. The comparatively low power of the anterior surface of the lens is also worthy of notice. In fact, it will be observed that it is nearly neutralized by the inner concave (posterior) surface of the cornea.

Summary :—

(*a*) A schematic eye is merely a model for comparison.

(*b*) A reduced eye is one simplified for the purpose of calculation.

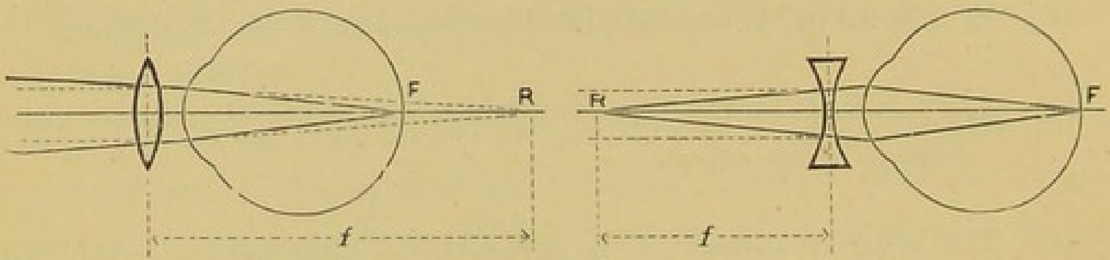
(*c*) The cardinal points of the reduced eye are reckoned from the anterior surface of the cornea.

(*d*) The anterior surface of the cornea is the principal refracting surface in the actual eye.

CHAPTER XXII.

POSITION OF CORRECTIVE LENSES.

WE have already seen that the far point (P.R.) of an eye is conjugate to the retina, and, moreover, that the focal point of the lens correcting the ametropia coincides with the far point. It is clear that such must be the case from Fig. 73, I and II. In each figure the position of the P.R. is



I. Fig. 73 II.

indicated by the letter R, and therefore, the eye is capable, without accommodating, of focussing this point R upon the retina at F. If, however, a distant object is to be seen clearly, a positive lens (I), or negative (II), of focal length f, must be placed in front of the eye. The distant object and far point (P.R.) are thus seen to be conjugate foci with respect to the corrective lens, and any movement of the convex lens away from the eye necessitates a *decrease* in power to retain the same positions for conjugate foci, while any movement of the concave lens from the eye necessitates an increase in power to retain the same positions for conjugate foci.

The first of these statements requires some qualification, for if light proceeding from any point o is to be focussed at a point o_1, and u and v, as usual, represent the first and second conjugate distances respectively, then the weakest possible convex lens that will focus light proceeding from o at the point o_1 must be situated midway between o and o_1. In other words v must equal u. For we have, for a convex lens producing a real image (convergent light),

$$F = V + U = \frac{1}{v} + \frac{1}{u} = \frac{u + v}{v\,u}$$

Now it is a well known rule of proportion that the *result* of the sum of two quantities divided by the product of the same two quantities has its minimum value when the two quantities are equal, providing the sum of the two quantities (in this case $u + v$) always remains constant. This can be verified by assigning to u and v actual values and keeping $u + v$ constant. Therefore when a *convex* corrective lens occupies a position midway between the far point and the distant object it will have a minimum value, the lens being the weakest one possible for correcting the ametropia present. For such a position of the corrective lens each conjugate distance would be just twice its focal length—the distant object and far point occupying symmetrical planes with respect to the corrective lens.

The above conclusions do not hold good for near vision and reading because the object viewed may be at a distance *less* than twice the focal length of the corrective lens when qualification is needed:—"Any movement of position of corrective lens necessitates a *decrease* in power to retain the same positions for conjugate foci, *providing the object is distant from the lens more than twice its focal length.*" To be quite precise we may say that if a positive corrective lens is of such a power as to give a focus upon the retina when near to the eye, then when it is withdrawn from the eye it will produce a focus in front of the retina, in other words, it will be *too strong in effect.* But if the convex lens passes the midway position, and, therefore, is situated nearer to the object viewed than to the far point of the eye, the reverse will be the case, because a weaker lens placed nearer the eye would do the same work.

These qualifying remarks do not apply to the case of withdrawing a negative (concave) lens from the eye, for such cannot possibly produce a real inverted image of the same size as the object, and, therefore, we cannot speak of symmetrical planes when referring to concave lenses, which can only produce a real image when they receive light of sufficient convergence. This must be artificially produced, for in nature all light is divergent, even that which, coming from a great distance, we term *parallel light.* Any movement in position of a corrective concave lens always necessitates an *increase* in power to retain the same positions of conjugate foci, evident from Fig. 73 II, for if we consider first the distant object (indicated by dotted lines) viewed through the concave lens, then as this is withdrawn from the eye f must of necessity decrease to retain the same position for conjugate foci. Consequently a lens at some distance from the eye must be equivalent to a weaker one placed closer to the eye. In other words when a concave lens is withdrawn from the eye it will produce a focus in front of the retina (providing it corrected the ametropia in the first instance) and, therefore will be *too weak in effect.* If we suppose the object to be a near one a similar effect is produced, because, although the distance between the object and the lens appreciably diminishes, this only assists in producing the same effect. That such must be the case will be realized if we imagine the corrective lens to be coincident with the near object viewed, for then no refraction can take place, so that the equivalent power of the lens is zero and an "infinitely great" increase in power is necessary to retain the same positions for conjugate foci, and this infinitely strong lens only does the work of a comparatively weak one placed close to the eye.

There are two other important features connected with the position of corrective lenses. Firstly, we should make it a rule wherever possible to place the corrective lens at 15 mm. distance from the cornea, that is, approximately coincident with the anterior focal point of the eye. In order to correct the ametropia its power must differ from that of one placed in contact with the cornea, which would be a *contact* lens, and although not possible for ordinary wear, is convenient in investigation, being known as the *equivalent contact* lens. Secondly, for varying distances of the object, the difference between the power of the contact lens and one at 15 mm. distance (each to correct the ametropia present) will not remain constant. This latter effect is of great importance, for the corrective lens which we place at 15 mm., perhaps with a statement emphasizing that it is for *constant* use, is kept in this one position, has but one power, and is employed in conjunction with the eye to view objects at varying distances.

For example, consider a + 4 D lens placed at 15 mm. from the cornea. Let us determine :—

(1) The power of the equivalent lens at the cornea for a distant object.

(2) The power of the equivalent lens at the cornea for a near object, which we will suppose is 250 mm. from the corrective lens 15 mm. in front of the cornea.

In (1) the + 4 D lens would focus light at a distance of 250 — 15 = 235 mm. behind the cornea. The equivalent power of the contact lens is, therefore, $\frac{1000}{235} = 4{\cdot}26$ dioptres for a distant object. In (2) where the object is 250 mm. from the + 4 D corrective lens, the light would emerge from the + 4 D lens parallel, (since $f = 250$ mm. for + 4 D). Hence the contact lens must have a focal length of 250 + 15 = 265 mm., and an equivalent power, therefore, of $\frac{1000}{265} = 3{\cdot}77$ dioptres.

Now let us take the case of a + 8 D under similar conditions. In (1) this + 8 D lens would focus light at a distance of 125 − 15 = 110 mm. behind the cornea. The equivalent power of the contact lens is, therefore, $\frac{1000}{110}$ = 9·09 dioptres for a distant object. In (2), where the object is 250 mm. from the + 8 D corrective lens, the light would be brought to a focus at 250 — 15 = 235 mm. behind the cornea. For the contact lens we have therefore, as conjugate distances

$$u = 250 + 15 = 265$$
$$v = 250 - 15 = 235$$

The equivalent power, therefore, is given by

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$
$$= \frac{1000}{235} + \frac{1000}{265}$$
$$= 4{\cdot}26 + 3{\cdot}77$$

= 8·03 dioptres for the near object, which is 250 mm. from the + 8 D lens at 15 mm. from cornea.

Working on these lines Mr. S. D. Chalmers* has drawn up the following table :—

Power of Lens.	Equivalent Lens at Cornea.		Power of Lens.	Equivalent Lens at Cornea.	
	Object at Infinity.	Object at 250 mm. from Lens.		Object at Infinity.	Object at 250 mm. from Lens.
+ 1	+ 1·02	+ ·90	− 1	− ·98	− ·88
+ 2	+ 2·06	+ 1·83	− 2	− 1·94	− 1·73
+ 3	+ 3·14	+ 2·79	− 3	− 2·87	− 2·57
+ 4	+ 4·26	+ 3·77	− 4	− 3·77	− 3·37
+ 5	+ 5·40	+ 4·79	− 5	− 4·65	− 4·16
+ 6	+ 6·60	+ 5·83	− 6	− 5·50	− 4·93
+ 7	+ 7·82	+ 6·91	− 7	− 6·34	
+ 8	+ 9·09	+ 8·03	− 8	− 7·14	
+ 9	+ 10·40	+ 9·17	− 9	− 7·93	
+ 10	+ 11·77	+ 10·37	− 10	− 8·70	

There are many points of interest in these tabulated results. First to be noticed is the change in the equivalent power for an object at 250 mm. between + 7 and + 8 D.

* Optical Society Transactions, 1907.

We are given—

Power of Lens.	*Twice Focal Length of Lens.*	Equivalent Lens at Cornea with *Object at 250 mm.*
+ 7	285·6	+ 6·91
+ 8	250·0	+ 8·03
+ 9	222·2	+ 9·17

With + 7 the equivalent lens is less, for + 8 it is almost identical, while for + 9 the power of the equivalent lens is more. This merely emphasize the midway position effect referred to earlier in the chapter.

For spherical corrections the effects indicated by these results are not probably of great importance, as accommodation would automatically counteract them. But for cylindrical and sphero-cylindrical corrections the effect, as Mr. Chalmers has pointed out, is very important. For example, suppose a corrective lens at 15 mm. from the cornea has a power of + 4 D Sph. ⌒ + 4 D Cyl., so that one chief meridian has + 4 D, and the other has + 8 D power. For a *distant object* this lens is equivalent to + 4·26 in one chief meridian, and + 9·09 in the other chief meridian, or to + 4·26 Sph. ⌒ + 4·83 Cyl. at the cornea, but for a *near object* the same lens is equivalent to + 3·77 in one chief meridian and + 8·03 in the other chief meridian, or to + 3·77 Sph. ⌒ + 4·26 Cyl. at the cornea.

Here again the spherical difference is unimportant, but the cylindrical difference of 0·57 dioptres is much too great to be neglected. The matter will be further dealt with in Chap. XXXIX.

So far we have referred to the position of corrective lenses rather as parts of a whole, in combination with the eye, than as influencing the optical properties of a system, such as they form with the refracting media of the organ and the air space between. It becomes necessary to consider them in this latter sense when we investigate the influence of their position upon the size of retinal images, and upon the total refractive power of the system, for we may have a case where, by moving a corrective lens from the eye its apparent power is increased, but the power of the system as a whole is thereby lessened. In Chapters XX. and XXI. it was laid down that conjugate distances were measured from P_1 and P_2, the principal points, whereas the relative sizes of object and image were governed by their distances from N_1 and N_2, the nodal planes. Further, we know that for distinct vision the object seen and the retinal image must be at conjugate points, and that the anterior focal distance is in air, while the posterior focal distance is measured entirely within the eyeball, except in some few types where P_2 is actually in front of the eye. Finally, it is evident that a displacement of any portion of the refracting system, by removal of a lens, or any addition to any portion, as in the exercise of accommodation, causes a displacement of the principal planes, and consequently also of the nodal planes.

For the purpose of illustration two extreme instances will be taken, the one a case of high myopia, and the other a case of aphakia from lens extraction.*

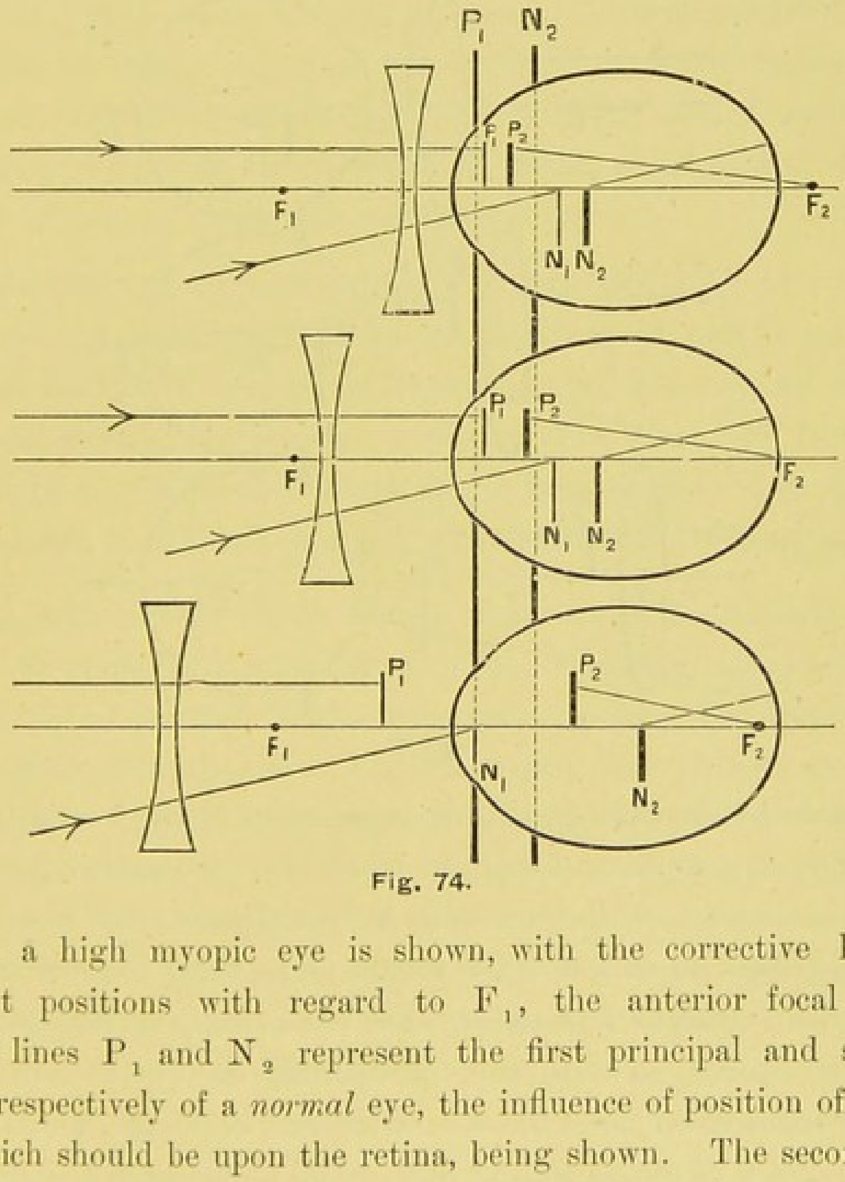


Fig. 74.

In Fig. 74 a high myopic eye is shown, with the corrective lens in three different positions with regard to F_1, the anterior focal point. The vertical lines P_1 and N_2 represent the first principal and second nodal planes respectively of a *normal* eye, the influence of position of the lens on F_2, which should be upon the retina, being shown. The secondary axis in each case is the same, so that tracing it back from the second nodal point the size of the retinal image can be estimated, and it is noticeable that, although the distance of the lens in the third position brings F_2 within the eye, yet the retinal image is actually lessened because N_2 has been also

* Proc. of the Optical Convention, 1905.

moved nearer to the retina in the opposite direction. The parallel light is shown incident to P_1 and refracted at P_2, and a striking feature is the widening out of the principal and nodal planes, to exactly the same extent in each case, so that from P_1 to P_2 is identical with the distance apart of N_1 and N_2. In this case, quite contrary to what we find in the next, the posterior focal length gradually lessens, and so the power as a whole increases as the influence of the lens decreases, as we saw in dealing with the removal of concave lenses from the eye.

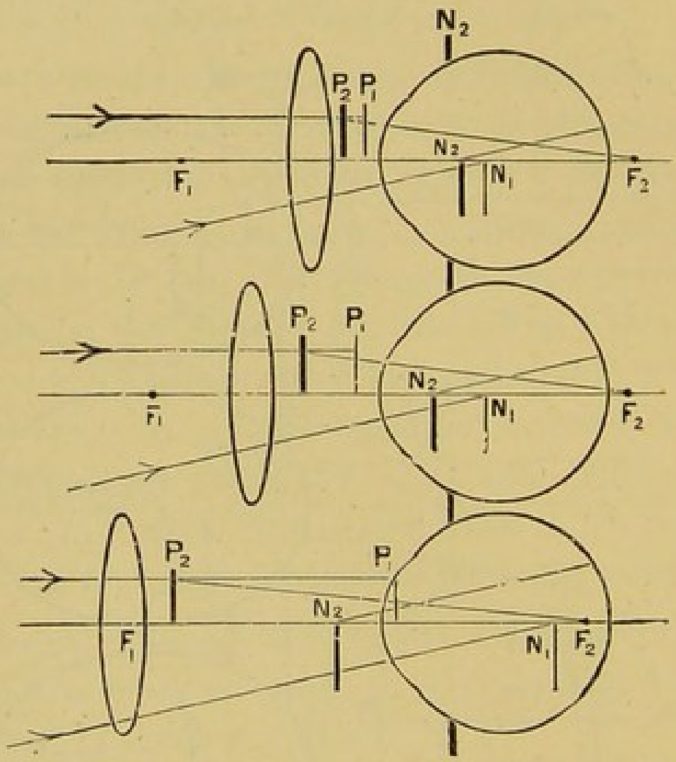


Fig 75.

The eyes represented in Fig. 75 are, in consequence of the loss of the crystalline lens, highly hyperopic, and entirely deprived of accommodation. The first feature noticeable is the reversal in position of the nodal planes and principal planes, in each case the *second* plane being towards incident light, and as, with withdrawal of the lens the focal length of the system increases P_2 moves rapidly outward, and consequently N_2 does the same. This has a very marked effect upon the size of the retinal image, which is regulated by the position of the second, or *back* nodal point, as it is sometimes called, although in this case it is actually in front. In both this figure and the last the course of the plane wave entering the system, shown by the line parallel to the axis, and also the position of the secondary axes, should be carefully studied, noting the transference in all cases from the first to the second plane, and if in any case we wished to place a single lens in position to represent the whole refracting system of eye and corrective lens it would be put at P_2, the distance between that and F_2 representing the posterior focal length. (Chap. XX.)

These diagrams show the necessity of placing the corrective lens as nearly as possible to the anterior focal point of the eye, so that the retinal image may be as nearly as possible the normal size, and comparing Figs. 74 and 75 the most striking facts are the differences created by removal of the two lenses upon the posterior focal distances of the two systems, and the greater differences in the size of the retinal images caused by such removal in high hyperopia than in high myopia. Although extreme types have been taken the same arguments hold good in ordinary cases, but to a less degree, provided accommodation is not used, and we see the necessity of always considering the position of nodal points when dealing with questions involving vision with corrective lenses.

Considering the effect of accommodation, it is clear that without a lens in front of the eye the posterior focal length is shortened and P moves towards the retina, so that N does the same, and images are reduced. If, instead of accommodating, the eye has a convex lens placed in front to enable objects to be seen without accommodation then P_2 and N_2 move away from the retina and images are enlarged, as in presbyopic corrections.

The above remarks *do not imply* that a single individual would perceive an object to be of one particular size with lenses varying in power, even if each lens were placed precisely at the anterior focal point. Dr. Lindsay Johnson has laid stress upon the point that if a certain lens corrects the ametropia present then a stronger or weaker one must give rise to circles of confusion which would stimulate the neighbouring cones, so that the object viewed, even if seen fairly clearly, will appear larger. Should the error so introduced be corrected by accommodation then this again will alter the size of the retinal image because the nodal point N_2 will shift, whereas the focal point F_2 will not. On the other hand all persons having a normal length of eyeball, and who wear their corrective lenses at the anterior focal point, have an image formed upon their retina of an identical size when the same object at a given distance is viewed.

In astigmatism, corrected by a lens in front of the eye, there is frequently trouble, because the retinal images vary in size in the different meridians. This is readily seen if we notice that there are always two principal meridians, one of highest and the other of least refraction, so that, from what has preceded, there should be two cylindrical lenses at different distances from the eye to produce equal proportion for the image. When the one meridian is hyperopic and the other myopic, as in mixed astigmatism, the defect is very noticeable, and wearers of the corrective lenses can rarely be relied upon to estimate exact proportion, because circles appear to them as oval in shape, and when the meridians are oblique, squares seem to be diamond shaped. In all cases of high degree, only a lens in actual contact with the cornea will give an approximate constancy in proportion.

Mr. Conrad Beck has pointed out a source of trouble which is likely to occur with toroidal (toric) lenses, and which experience has shown to exist. Their position in front of the eye has a greater effect upon the displacement of the nodal planes than ordinary sphero-cylindrical combinations, and so the retinal images vary more, especially when the error of refraction is large.

Summary:—

(*a*) When a + lens occupies a position midway between the *p.r.* and a *distant* object it will have a minimum value.

(*b*) Any movement of a + lens away from the eye necessitates a decrease in power to retain the same positions for conjugate foci, provided the object is distant from the lens more than twice its focal length.

(*c*) Any movement away of a corrective — lens *always* necessitates an increase in power to retain the same positions for conjugate foci.

(*d*) The position of the object viewed affects the power of a corrective lens.

(*e*) In astigmatism no lens, except actually in contact with the cornea, gives images propoitionately correct.

CHAPTER XXIII.

AIDS TO NORMAL VISION.

A DISTINCTION must be made between the effect of lenses placed in front of the eye in order to correct any ametropia present, and the effect of lenses either single, as in the reading glass and hand magnifier (simple microscope), or combined, as in the telescope, field-glass and microscope. In the former case the correction of the ametropia does not imply a difference in the apparent size of the object, for except in a few cases the retinal image is normal in size. But in the latter case the apparent size of the object is usually increased, and on this account the increment is an aid to normal vision, the apparent size of the *virtual* image projected by the eye being greater than that of the object seen by direct vision.

This apparent enlargement of the object is termed magnification, and we must note the difference between magnification and magnification with resolving power. This is clearly illustrated in the case of a bright star seen by the naked eye, and afterwards viewed through a telescope of moderate power, because the peculiar stellate appearance in the first case causes the actual object to appear larger than the well defined telescopic image. Again, in many cases of myopia the retinal image of an object, as seen within the far point of the uncorrected eye, is much larger than that of the emmetrope, the pathological stretching of the myopic retina, however, causes adjacent points to be further removed, without any filling in, as it were, of the interspaces, because the retinal elements are not so closely packed as in emmetropia (Chap. VIII.), so that resolution may easily be subnormal.

We may give an example of actual magnification to illustrate this, and also to show that magnification as here understood is always *linear*, and not measured by area or cubical capacity. Suppose that a scale is divided into millimetres and also tenths of a millimetre. With a certain lens it would be just possible to recognise the finer divisions, and it is conceivable that in some forms of ametropia we might get the same enlargement of the millimetre division without the recognition of the separation into tenths.

It has been stated that the images seen by means of aids to normal vision are virtual ones, and so they cannot be readily measured. The difficulty is increased by the fact that we cannot decide at what distance from the eye they are formed, in other words to what distance they are projected. If a magnifying glass of about + 12 D be taken, and a small piece of ruled foolscap be viewed lying upon a dull black background, the lines may be focussed and magnified, but, providing the paper does not overlap the field of view through the lens, the lines appear to be further from the eye than the dull background; whereas, if the small piece of paper be similarly viewed when resting upon a whole sheet of the same, the lines appear to be closer to the eye, the magnification suggesting nearness in the latter case, whereas in the former there is nothing for comparison.

It is necessary, therefore, to arbitrarily fix a distance to which virtual images shall be assumed to be projected, and this is taken by universal consent at 10 inches (25 cm.) from the eye (plane of the pupil—eyepoint of the instrument), a distance suitable for distinct near vision in all cases where near objects are concerned, but not applicable to vision of distant objects as seen through the telescope, etc.

In the case of instruments employed to view near objects magnification is defined as the ratio of the linear dimension of the virtual image at 25 cm. distance, to that of the object when placed at the same distance and viewed direct. This is a conventional magnification and does not represent the true value which is given by the ratio of the sizes of the retinal images, or $\frac{\theta_2}{\theta_1}$ for any instrument, where θ_2 represents the angle subtended by the virtual image, and θ_1 that subtended by the object. The conventional method of expressing magnification is very important for purposes of comparison, and it *may* represent the apparent magnification, especially in the use of the reading glass. The *apparent* differs from the conventional magnification, and may be defined as the ratio of the linear dimension of the virtual image, when projected to the actual object plane, to that of the object in its actual position. It is also estimated by the double vision method where one eye views the virtual image through the lens and the other views the object direct, comparing the relative sizes.

Assuming a virtual image to be projected, in which case the object must be just within the focal point of the lens system, and occupying a position less than 25 cm. distance from the eye, the conventional value must exceed the apparent, whereas with the object at a greater distance than 25 cm., the reverse will be the case, while, with the object at 25 cm. the two values will agree.

This is illustrated in Fig. 76, where A B is the object and A_1 B_1 the virtual image at 25 cm. distance. Supposing A B to be outside the near point of distinct vision, so that it may be clearly seen, A B would subtend a larger angle at P than would A_3 B_3, of the same size at the conventional distance, and, consequently, the conventional *m* will always be greater than the apparent *m*.

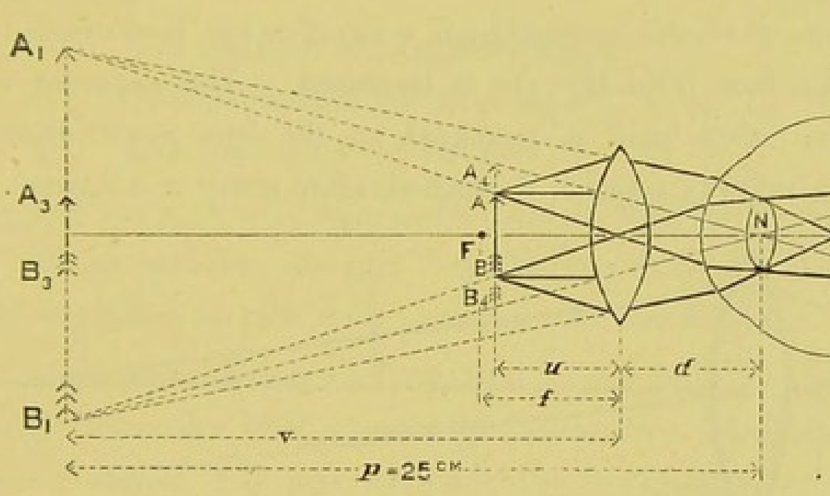


Fig. 76.

To put the matter clearly, suppose we place a millimetre rule at 10 inches from the eyes of an emmetropic youth of 16 years, who will be able to accommodate easily up to within about 4 inches from the eye. He now views an object of 1 mm. length with a lens of + 8 D placed ½ inch from one eye. The object then will be just under 5 inches from the lens, and if with the free eye he views the object it will be projected upon the scale, while the virtual image will also be seen upon the scale and will be only a trifle larger (1·1 times approximately). This is the apparent magnification. The conventional magnification will be obtained by the same double vision method, except that the free eye views the scale and notes how many mms. the virtual image of the 1 mm. object covers ; the number will be nearly 3, each mm. of the scale representing the size of the object as it appears when at 10 inches (25 cm.) from the eye. If, as often happens with the reading glass, the object is actually at 25 cm. from the eye then conventional and apparent magnification correspond.

The conventional magnification is given by :—

$$m = \frac{I}{O} = \frac{v}{u} \quad \text{but } u = \frac{f\,v}{f + v}$$

$$= \frac{v\,(f + v)}{f\,v}$$

$$= 1 + \frac{v}{f} \left(\text{or } 1 + \frac{F}{V}\right)$$

If we represent the distance of the lens from the eye by d, and the distance of normal distinct vision by p, then :—

$$m = 1 + \frac{p - d}{f}$$

from which the table at the end of the book is calculated.

From this it follows that the conventional magnification is decreased as the distance of the lens from the eye is increased. The apparent magnification, on the other hand is increased as the lens is withdrawn from the eye, until a midway position is reached, after which it decreases.

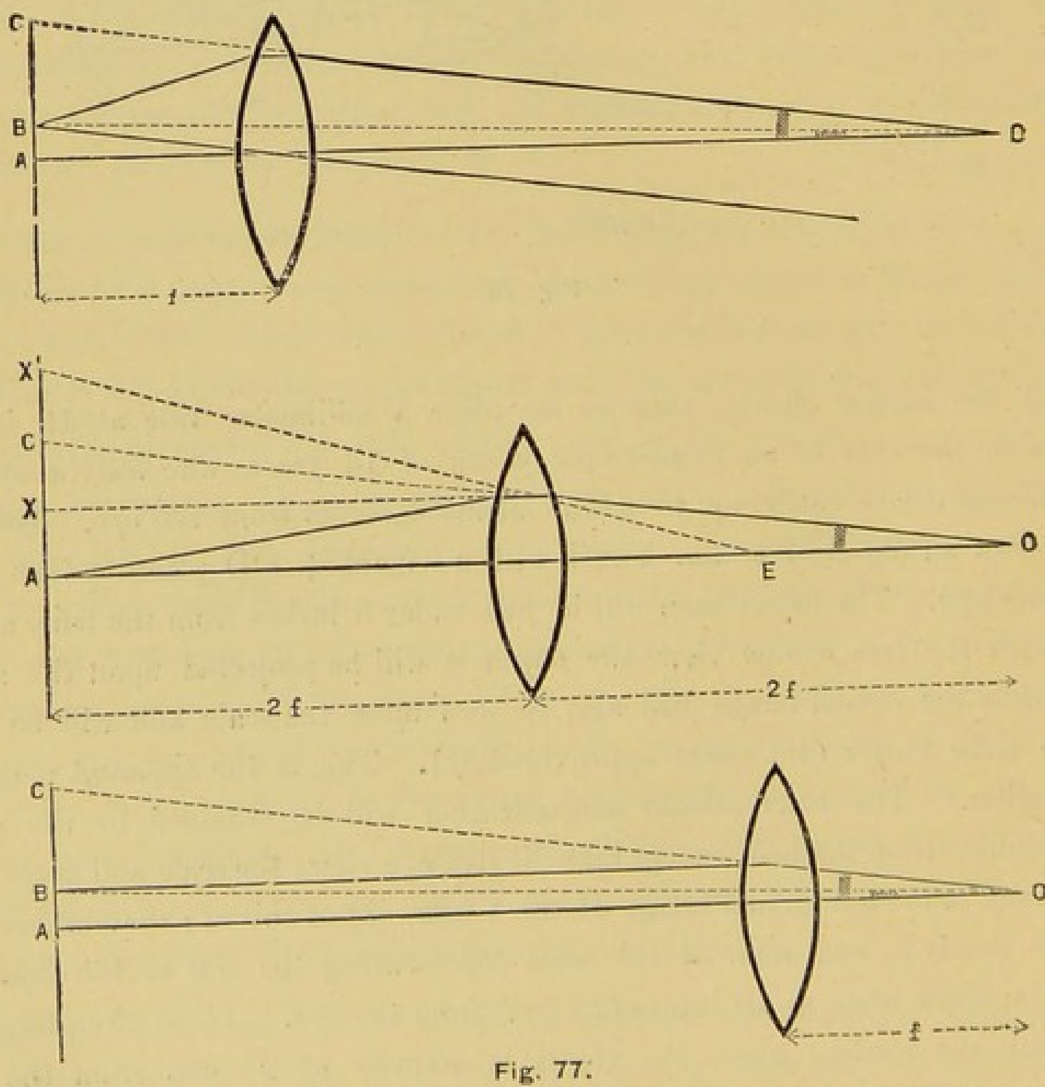


Fig. 77.

The angles are shaded, θ_2 being the larger and θ_1 the smaller.

It is of considerable importance to consider the greatest effect produced by a convex lens placed between an object and the eye. In Fig. 77 A C represents an object such as a page of print, and O the optical centre (back nodal point) of the refracting system of the eye, and let A O equal four times the focal length of the lens shown, for the particular case we are considering. Then the print and the eye are in symmetrical planes when the lens is midway between them, as in the second figure, while in the first and third the print and eye respectively are in the focal planes of the lens.

It is proposed to show that, for a single convex lens, the value of m depends upon :—

(*a*) The distance of lens from object.

(*b*) The distance of eye from object.

(*c*) The focal power of the lens.

If we suppose the lens to be thin and in contact with the object, light apparently, as well as actually, diverges from the object itself, and $\theta_2 = \theta_1$, giving unit magnification, the image being in the object plane.

With the lens at a distance of its focal length from the object light emerges parallel from the lens, apparently coming from an infinite distance, and a smaller object A B now subtends the same angle as A C, as the first diagram shows.

But $f = \frac{1}{4}$ AO, therefore AB $= \frac{1}{4}$ AC and $m = \frac{\theta_2}{\theta_1} = \frac{\text{AC}}{\text{AB}} = 4.$

Therefore the magnification is four times, and as the emergent light is parallel the object is distinctly seen.

When the lens occupies the midway position (twice its focal length) AO $= 4f$, and light converges to O in the eye, crosses over and floods the retina with light, so that an infinitely small point A on the axis will subtend the angle θ_2, hence nothing definite will be visible, the magnification being infinite and useless.

In the third illustration we have the converse of the first, light diverging from the object emerging convergent from the lens, but as the eye cannot adapt itself to focus convergent light the object will not be seen clearly. As AB apparently subtends the angle θ_2 and $f = \frac{1}{4}$ AO $\therefore m = \frac{\theta_2}{\theta_1} = \frac{\text{AC}}{\text{AB}} = 4,$ as in the first case. Finally, with the lens just in front of the eye (15 mm.), its optical centre being coincident with the anterior focal point, the *real* inverted image on the retina will be normal in size, because, as explained in

Chapter XXII, the nodal point N_2 of the system (lens and eye) will move forward by an amount identical with the movement of F_2, the posterior focal point. If the eye is emmetropic the real image will be formed in front of the retina, and the object will appear too large and blurred, but if the lens happens to correct the ametropia there is perfect unit magnification. It is therefore evident that when the distance of object to eye is equal to $4f$ then m increases from unity to infinity, and decreases from infinity to unity, as the lens is moved from the object to the eye.

Let us suppose now that AO is less than $4f$; then, for any equivalent position of the lens the magnifying power will be less, although it will still produce the maximum value when in the midway position. Thus, if in the second diagram the eye is moved forward to E, a distance from the lens equal to its focal length, then an object AX is seen as AX′, the magnification being obviously three times. If now the lens is placed midway between A and E, m will have its greatest value, but it will not be infinitely great, as when the eye was at O, because the object seen under the new angle θ_2 would be of some considerable size.

When AO is greater than $4f$, the lens, when in certain positions will cause light diverging from the object to *converge* to a point in front of the eye, thus forming a *real inverted* aerial image, and light diverging from this will enter the eye, the magnification being given by the ratio of the conjugate distances from the lens $\left(m = \frac{v}{u}\right)$, so that the magnification may be negative, the image being less than the object. When the lens is in the midway position for conjugate foci the object might just as well be inverted, placed in the image plane, and viewed direct.

With any given position of the lens which enables a virtual image to be projected, m increases with the distance between object and eye. In the first diagram, where the lens is at its focal length from the object, and the eye at O, $m = 4$, but if the eye recedes from O, it is clear that light still emerges parallel from the lens, and therefore from any point of the object, as B for instance, every path makes the same angle with the axis and so θ_2 remains constant. As the eye recedes it is clear that θ_1 diminishes and, therefore, m $\left(\frac{\theta_2}{\theta_1}\right)$ increases; the field of view gets less and less and becomes infinitely small when m becomes infinitely great.

From (1) Fig. 77 it must be obvious that m increases with an increase in the focal power of the lens, providing a virtual image is viewed. For as f decreases any oblique path from some point in the object such as B will be bent to a greater extent, consequently any given object will be seen under a greater angle than previously.

We are now in a position to study, with regard to magnification, etc., the effect of placing in front of the eye various optical aids to normal vision. Although it has been shown that the instrument and the eye as a whole can be readily dealt with on the Gauss system, the subject requires some further investigation. The simplest aids to vision are the hand-magnifier and reading-glass, the first always held close to the eye and the other at some distance away. The hand-magnifier or simple microscope has already been dealt with somewhat fully, magnification being expressed conventionally by the equation $m = 1 + \frac{F}{V}$. The reading-glass is identical in action, Fig. 76 illustrating the formation of the real retinal image A_2 B_2 and the projected virtual image A_1 B_1. It is important to note that if we take any point of the object nearer the axis that A or B the path of the emergent beams will not make so great an angle with it, and a point actually upon the axis will give a path parallel with it. This indicates why the field of view lessens as the eye is withdrawn from the lens, for clearly such beams as shown in the diagram could not enter the pupil, but only those whose path was nearer the axis of the entire system. Consequently a reading-glass must have a large aperture. This, owing to aberration, limits its power, which in practice is usually of the order of 4D. The reading-glass should be employed in the midway position (2) Fig. 77, so that a maximum value of m may be obtained with a minimum of power. The crossing point of the greatest number of rays emerging from the system is termed the eye-point, N in the accompanying figure, and this is the position of greatest advantage for field of view and illumination ; an important matter in the microscope, opera-glass, etc.

The Binocular Magnifier is an arrangement by which a lens is placed before each eye and decentered inwards, so as to equalize the functions of accommodation and convergence.

In Fig. 77A a convenient form of such instrument is shown. This is made by Messrs. C. W. Dixey and Son, and consists of two decentered convex lenses, so placed that their planes are at right angles to the ocular visual axes when the object is viewed. A suitable bar allows of a movement towards or away from the eyes, and is attached to a frame which fits upon the face. A small vertical folding diaphragm in the median plane prevents confusion during use of the lenses.

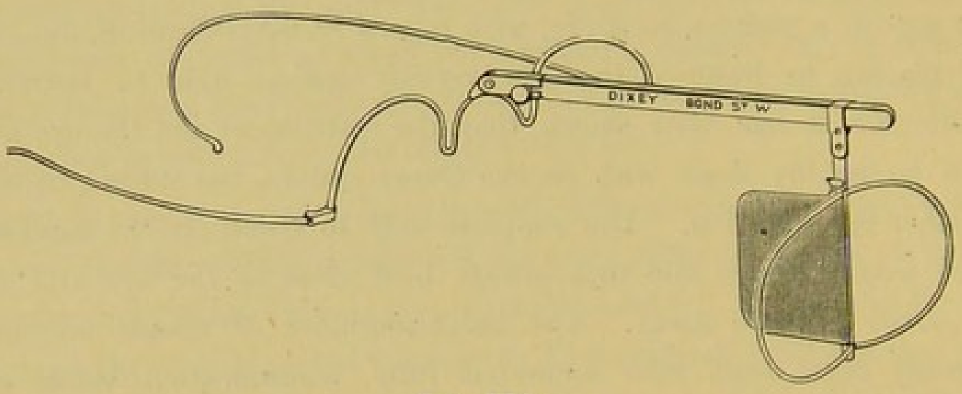


Fig. 77A.

The Astronomical Telescope, employed to view distant objects, and giving an inverted image, may have its magnification defined as the ratio of the apparent size of the object seen through the instrument to the apparent size seen direct. The tube length equals the sum of the focal lengths of eyepiece and objective, which condition ($t = f_0 + f_2$) gives parallel emergent light. The instrument should be adjusted by *racking in* and not racking out, otherwise accommodation will be brought into play ; if t exceeds $f_0 + f_2$ then emergent light will be convergent and only suitable for hyperopic eyes, while if t is less than $f_0 + f_2$ the divergent light will be suitable for myopes, the difference of tube length of any particular instrument from its normal indicating approximately the amount of ametropia present. Thus, with a telescope whose objective is + 2D and ocular + 40D, t will be $(50 + 2{\cdot}5) = 52{\cdot}5$ cm. Suppose it is racked in 5 mm. then parallel incident light focusses at 50 cm. from the objective and at the eyepiece will have a divergence of $\left(\frac{100}{52-50}\right) = 50$D. As the eyepiece is + 40D, clearly the emergent light would suit a myope of 10D provided the eye is placed near the instrument.

The Terrestrial Telescope is essentially like the foregoing except than a lens or lens system is placed between the real image formed by the objective and the eyepiece, the tube length being extended. This is done in order to give an erect image.

The Galilean Telescope or Opera Glass has a negative eyepiece which is placed a distance equal to its focal length inside the focal point of the objective in order to obtain parallel emergent light. The tube length is given by $f_O - f_E$, and the image is erect.

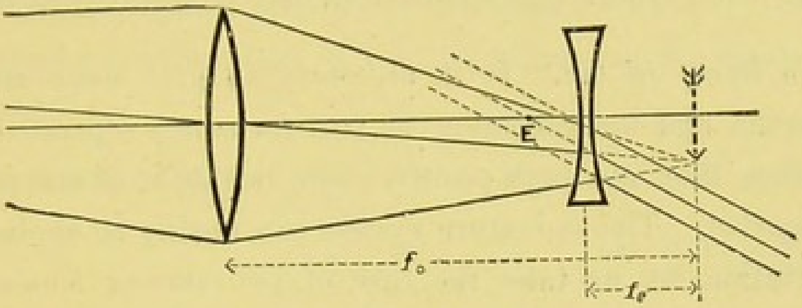


Fig 78.

Fig. 78 shows the real inverted image of a distant object which would be formed if the convergent light had not met the concave lens which makes it parallel, and an emergent parallel pencil is illustrated, from which it is seen that the true eyepoint E is consistently virtual, which prevents the eye being placed in its true position, and causes a limited field of view, the only defect of an excellent instrument. Its construction is simplified by the fact that the negative eyepiece has the opposite chromatic effect to the objective.

Suppose that such an instrument has an objective of + 5D and an eyepiece of − 40D, then the tube length will be (20 − 2·5) = 17·5 cm. for parallel emergent light, and if it be then screwed *in* 5 mm. we shall have at the eyepiece $\left(\frac{100}{20-17}\right) = 33\cdot\dot{3}$D, this being the convergence of the light from the objective. But as the eyepiece is − 40D, the emergent light will have a divergence of $6\cdot\dot{6}$D.

If the tube be screwed *out* 5 mm. from the position for parallel emergent light then a convergence of $\left(\frac{100}{20-18}\right) = 50$D is only partly neutralized by the − 40D of the eyepiece, and the emergent light is convergent 10D, and, just as with the astronomical telescope, myopia and hyperopia may be in effect corrected by the amount of *draw* which gives the necessary divergence or convergence to emergent light, provided no accommodation is employed. For this reason an opera glass should be opened to its full extent and gently racked in. Optometers have been constructed on this principle, but they are not reliable because of the increase in magnifying power as the convex lens is withdrawn from the eye.

The Prism Binocular is exactly like an astronomical telescope the real image of which is erected by means of two totally reflecting prisms, causing a loss of light but giving a large field of view. In these, as in all other cases, a correcting lens, spherical or cylindrical, may be inserted in the eyepiece.

Separated thin lenses in air. It is necessary to give some attention to the focal lengths and magnification of two (or more) separated thin lenses in air, whether they are both positive, both negative, or one positive and the other negative. The curvature system can readily be applied here, and as an illustration let us take the case of two convex lenses L_1 and L_2 in

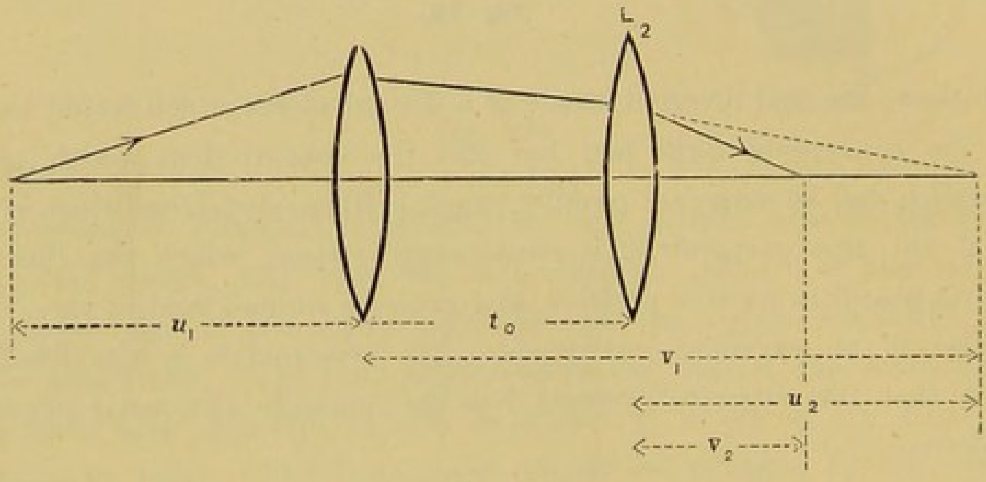


Fig 79.

Fig. 79, the first being + 10 D, the second + 12 D, and the interval between them 25 mm. If we imagine parallel light passing from left to right it receives a convergence of 10 D at L_1 and would focus at 100 mm. upon the other side, therefore when it arrives at L it actually has a convergence of $\left(\frac{1000}{100-25}\right) = 13\dot{\cdot}3$ D. As it emerges from L_2 it will have received the extra convergence due to this lens and now is $(13\dot{\cdot}3 + 12)$ $= 25\dot{\cdot}3$ D, coming to a focus at $\left(\frac{1000}{25\dot{\cdot}3}\right)$ = approx. 39·5 mm. from L_2. If we suppose the parallel light to pass from right to left we should find the focus at about 36·8 mm. from L_1, by a similar calculation, and as these two measurements depend upon the relative powers of the lenses, *only being equal when the lenses are of equal curvatures, powers and signs*, they are denoted as the *first back focal length*, measured from L_1, and the *second back focal length* measured from L_2.

It is evident, however, that such a combination must have an equivalent focus, the same upon both sides, measured from the principal points, which in such a case coincide with the nodal points (Chapter XX), so that we must carefully distinguish between f_E, f_{B1} and f_{B2}, and also between F_E, F_{B1} and F_{B2}.

Below are given the equations which show these differences, the details being deduced from a consideration of Fig. 79 supposing the incident light to be parallel :—

Equiv. focal length $f_E = \frac{f_1 f_2}{f_1 + f_2 - t}$ $\therefore$ $F_E = F_1 + F_2 - F_1 F_2 t$. 1.

1st back ,, $f_{B1} = \frac{f_2 (f_1 - t)}{f_1 + f_2 - t}$ $\therefore$ $F_{B1} = \frac{F_1 + F_2 - F_1 F_2 t}{1 - t F_1}$. 2.

2nd back ,, $f_{B2} = \frac{f_1 (f_2 - t)}{f_1 + f_2 - t}$ $\therefore$ $F_{B2} = \frac{F_1 + F_2 - F_1 F_2 t}{1 - t F_2}$. 3.

From these it is clear that we can obtain the position of the principal points by subtracting 2 from 1 and 3 from 1, the differences expressing the distances from the surfaces of the lenses inwards.

If we represent the magnification due to L_1 by m_1 and that due to L_2 by m_2 then $m = m_1 m_2 = \frac{v_1}{u_1} \times \frac{v_2}{u_2} = \frac{U_1 U_2}{V_1 V_2}$.

Summary :—

(*a*) The magnification caused by high ametropia may not have the resolving power of true magnification.

(*b*) Magnification is given by $m = \frac{\theta_2}{\theta_1}$.

(*c*) Conventional magnification assumes that the virtual image is formed at a distance of 25 mm. from the eye, for the purposes of comparison. It is given by $m = 1 + \frac{(p - d)}{f}$, and is sometimes the apparent value.

(*d*) The maximum magnification with a minimum of power is obtained when the lens is midway between object and eye.

(*e*) For an astronomical telescope $t = f_o + f$.

(*f*) For the opera glass $t = f_o - f_E$.

(*g*) The equivalent focal length of a lens system must be carefully distinguished from the first and second back focal lengths.

Section IV.

The Testing Room.

CHAPTER XXIV.

EQUIPMENT AND FITTING.

THE room where sight testing is to be done is better entirely separate from the shop of the retail optician, so that the necessary privacy and quietude may be obtained, and such room is always most conveniently situated on the ground floor, because of the inconveniences of stairs to nervous, infirm or aged clients.

Usually there is no choice with regard to position of windows, but these are better when facing in a northerly direction, and should be furnished with blinds or curtains, so that the room may be entirely darkened when necessary. There are very few cases where daylight can be satisfactorily used in testing, nor is this wise even when position and circumstances are most favourable because the intensity of light varies so much in this country, and tests taken at different times may vary because of the illumination.

The length of the apartment should, theoretically, be 20 feet or over, but good work can be done at 18, 16, or even 14 feet, but no less distance is permissible for direct testing. When, however, the test-types are reversed, then a mirror may be used to reflect them, and any distance from 10 to 7 feet will serve. In a room of 14 feet, owing to a slight divergence of the paths of light from the type, we get results incorrect by about 0·25D, plus lenses too strong, and minus lenses too weak being selected. With young people such an error is often an advantage, tending to the fuller correction of H, and the under correction of M by a corresponding amount, but with older clients dissatisfaction or discomfort might result, and allowance for the discrepancy due to distance must be made when calculating their corrections.

When reversed type is used it should be hung exactly behind and over the patient's head, and the mirror fixed at the requisite distance opposite, preferably 10 feet, and should be tilted forward at the top about 4° or 5°, so that the incident and reflected paths of light may be as nearly as possible normal to the mirror, the object being to lessen as much as possible the slight confusion due to the faint image from the front surface of the glass, which overlaps the primary image from the silvered surface. It should be observed that vertical lines in the test will not be doubled, and these are the most important, but horizontal are certain to be slightly so, and consequently where the cylinder axis is placed in that position acuity may not be so good as in testing without a mirror. It may be reckoned generally that a mirror will make a difference with some clients such that, whereas $\frac{6}{5}$ might be obtained with direct testing, $\frac{6}{4}$ is the best with reversed type, but in lower acuities the difference cannot be estimated by the usual types.

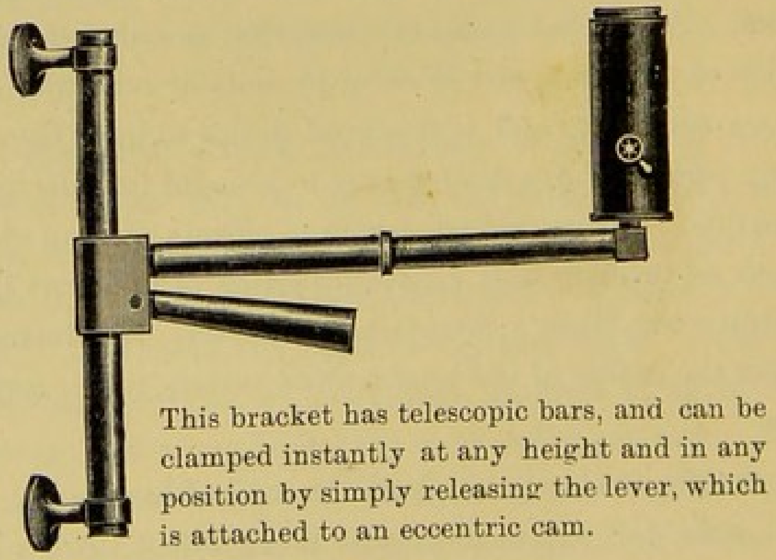
Where a mirror is unavoidable choice has to be made between a large one, which gives a better idea of distance, and apparent length to the room, and one which only allows the reflected image of the type to be seen, and generally the latter is preferable in a darkened room, because, in many cases, the client is apt to have his attention diverted to his own reflection rather than to the types.

In Chapter VIII the influence of lighting upon visual acuity was referred to, and from this it is evident that good illumination of the test type is essential. As a rule two electric lamps or incandescent gas lights, one on each side of the chart, and shielded by suitable reflectors from the client's view, are sufficient, and it is a good device to have the chart movable, so that any particular line desired may be brought into the region of maximum illumination. Some, indeed, favour a curtain, with an oblong aperture, so arranged as to allow only a certain portion of the chart to be seen, and so concentrate the client's attention. This has the further advantage of lessening the extent of the bright white surface, which may appear dazzling to some.

Everything about a testing room should be devised to give the idea of distance, a good ratio for length to breadth being 2 to 1, with a high ceiling, and extraneous ornaments and furniture, except what is required for instruments and testing should be avoided, as they distract the attention in many cases, and lessen the professional appearance of the place. The ceiling should be white, and if boarded and painted, zinc white may be used in preference to white lead, as it is not blackened by the fumes of gas or coal. The walls, on the other hand, should be coloured with tints restful to the eye, or of low reflective power. Some refractionists prefer slate colour or sea green, while others prefer a chocolate shade, as being warmer in appearance, and only reflecting a trifling amount of incident light.

Carpets are not suitable as floor coverings for a testing room, in which every endeavour should be made to eliminate dust, which settles upon test types and instruments, causing much trouble, and interfering with good work. For this reason the best covering is good thick cork linoleum, which is warm to the feet, and can be cleaned with a damp floor cloth. No glaring colours or obtrusive patterns should be chosen in any case, and all should harmonize.

The chair for the client under test should be especially comfortable, preferably of padded leather, and so arranged as to induce an upright position for the body; whilst the seat for the optician during retinoscopy is very convenient if it rises like a piano stool, a style which will serve well also for the client and operator in keratometry, while chairs should be provided for such friends as accompany clients in the testing room. Some provision must be made for the trial case. and this is best placed to the right hand of the client near where the optician stands in testing, and if frame fitting is done in the same room, a stand with the desk necessary for record books may be arranged.



This bracket has telescopic bars, and can be clamped instantly at any height and in any position by simply releasing the lever, which is attached to an eccentric cam.

Fig. 80.

Mackinney's Ophthalmic Bracket with Thorington Chimney.

The outfit of an optician should comprise test case, wall test type, astigmatic test fan, hand type, centimetre tape, retinoscope and chimney, and also concave mirrors and condenser for opthalmoscopy, ophthalmometer, perimeter, phorometer, binocular vision and colour perception tests, &c., where necessary. In addition, an ophthalmic electric or gas bracket (Fig. 80) is most desirable, and should be fixed a little above and to one side of the client's head, in such a position that it may readily be manipulated; in fact all tests should be so arranged as to cause a minimum of inconvenience in use.

A table, with hand-mirrors for client's inspection of frames in position upon the face, music, railway guides, hymn books, work baskets with a few samples of fine material, and needles, with cotton, may very advantageously be added for the benefit of presbyopes and others in certain occupations, while upon the walls suitably framed interesting optical diagrams and illustrations may be placed to relieve the bareness, where such is apparent.

Summary :—

(*a*) The room must be as near 20 feet long as possible.

(*b*) If a mirror is used the type must be reversed.

(*c*) Arrangements must exist for darkening the room.

(*d*) Convenience in the use of apparatus must be studied.

Chapter XXV.

OBJECTS AND METHODS OF TESTING.

CLIENTS who visit an optician do so usually for one of two purposes; either they come for glasses to aid the sight and improve its character, or they come for enlightenment and advice on some condition which they do not understand, and about which they feel somewhat alarmed. In either case they seek the aid of the optician on account of the special knowledge which they believe him to possess in matters pertaining to human vision.

The objects of all testing are to find out, in a scientific and orderly manner, how far the eyes tested depart from the normal condition of healthy emmetropic organs. To ascertain this, every test made should have some definite purpose in view, and there should be no haphazard or slipshod application of test methods, but all should be conducted on systematic scientific principles. Such testing may be regarded as consisting of three stages :—

1.—Outward inspection of the eyes and their appendages.

2.—Subjective testing of vision, refraction, accommodation, and convergence.

3.—Objective testing for astigmatism, errors of refraction, opacities of the media, and lesions or abnormalities in the fundus, etc.

In the first, the objects are to ascertain from actual observation the outward condition of the visual organs, and in this inspection any very extraordinary state of affairs attracts immediate notice, and saves a great deal of valuable time. Suppose, for instance, that in a certain case the pupils appear unduly large, a suspicion is immediately raised as to the possibility that there *may* have been the recent application of a mydriatic, if the client is of youthful age, or that there *may* be a condition of paralysis of accommodation, or that the eye *may* be considerably myopic, or possibly, that some nervous disease, ocular or bodily in character, *may* be present. An inflamed eye with a dilated pupil, in older people, will raise a suspicion of that most dreaded disease *glaucoma*, for which the optician should ever be on the alert. If such a suspicion arises, the tension of the eye may be estimated by touching the sclerotic through the closed lids, whilst the client directs his gaze downwards, and if the eye varies from the normal, either by being too hard or too soft, the client should immediately consult an oculist. It is necessary to make the test with the *greatest delicacy* in order not to cause pain, and it should only be attempted as confirmatory in certain *dubious* cases. Enough has been said to show the desirability of such an external examination of the eyes as a preliminary to all optical testing.

The second series of tests is subjective, and these depend for their success upon the client's own observations and statements, subject to the guiding questions and organized methods of the optician. The primary object is to determine the condition of vision, as manifest to the client when he is entirely without artificial aid, and under the most favourable optical conditions. If V. is found to be normal, tests are made to discover whether it is so by virtue of an emmetropic condition or by means of exerted accommodation. On the other hand, should V. be sub-normal, tests are made to determine *whether the defect is due to some refractive error or to some physiological cause.* If the former, further tests are made to ascertain the nature and amount of the error, and the object of a correction must be to place the far point of the eye at infinity, for every meridian. This accomplished, accommodation and convergence must be tested *at the near point.*

Refraction and accommodation are corrected by means of lenses, but difficulties of convergence are relieved by means of prisms, which can be adapted so as to increase or diminish convergence. It will be seen that in subjective testing the procedure must be systematic and in definite order, because certain conditions are diagnosed by the *exclusion* of others, and dependence is placed throughout upon the intelligence and observation of the client and the replies he gives to questions put during the tests.

Subjective tests are also made for colour perception, binocular vision, the field of vision, the amplitude of convergence, the amplitude of accommodation, muscular imbalance, paralytic diplopia, hemianopsia, light perception, scotomata, ocular paralyses, spasm of accommodation, and simulated amblyopia. Space forbids the discussion here of the methods involved in all these cases, many of which will, however, be found described in other chapters. The object in every instance is to estimate the condition by *comparison with an accepted standard in normal cases*, and the value of the test depends entirely upon the accuracy of the observations made. The optician should endeavour to make sure that all his questions are clearly put *and properly understood by the client*, because mutual misunderstanding of each other's meaning elicits answers which vitiate results most carefully obtained, and so render the tests fallacious.

Objective methods are those which can be carried out without the need of questioning the client, and it follows that they are invaluable in dealing with the deaf and dumb, the amblyopic and illiterate, the stupid and imbecile, and any person with whose language we are not familiar. The objects of such testing vary considerably with the character of the tests themselves, so also the methods, which are not precisely the same in any two of them. One of the most popular and most accurate of the objective tests is that known as retinoscopy or the 'shadow test,' the aim of which is to measure the refraction of the eyes when accommodation is at its minimum. For this purpose it is conducted in a darkened room, which serves the double purpose of dilating the pupil and relaxing the accommodation (for darkness is the most perfect of all mydriatics), and at the same time allowing the retinal reflex to appear more brilliant to the eye of the observer. The principles and practice are explained in Chapter XXXV.

Another objective test is the indirect ophthalmoscopic examination for making a rapid inspection of the condition of the optic disc and fundus, and for gaining a rough idea of the refractive condition. An inverted image of the fundus is obtained, magnified about *five* times, the test being easily carried out after a little practice. In the case of aged clients, with small pupils and hazy media, it is somewhat difficult; with young people, on the contrary, it is generally easy. The direct ophthalmoscopic examination is for the more detailed and minute inspection of the fundus and media, being also used in conjunction with lenses, for estimating the refraction. By this means an upright image of the fundus is viewed, which is magnified about 17 diameters, but the field of view is about 4 times less than by the indirect method.

The ophthalmoscope is the only instrument by which we can study the condition of the interior of a living eye. The objects for which it is employed by the optician are to obtain such information as to the internal condition as will indicate obvious reasons for failure to obtain useful vision by lenses, and to indicate whether certain cases of defective sight should be referred to an oculist. As an instrument for estimating refraction it is not so much used as formerly, retinoscopy being easier, more convenient, and accurate. The satisfactory use of the ophthalmoscope requires long and steady practice, and considerable study of the normal fundus in all its *many varieties*, prior to attempting to recognise its abnormal conditions and unhealthy states.

Another objective test is the use of the ophthalmometer in order to ascertain the nature of the curvature of the corneal surface. By means of this instrument curvature can be estimated in every meridian, and so it affords a very ready means of finding the position of the principal meridians in astigmatism, and likewise the amount of difference between their curvatures, which *constitutes* the astigmatism. The theory and practical use of the instrument will be discussed in Chapter XXXVI; here we will content ourselves by noting that it does not show the amount of astigmatism at the retina, therefore its findings are not always indicative of the *total* astigmatism, and cylindrical lenses for its correction cannot usually be fitted from the readings of the ophthalmometer alone. Indeed, it is not safe to do so in any case, but still this forms a guide to the approximate correction required. It also shows, in a most beautiful manner, all cases of irregular corneal astigmatism and conical cornea. With regard to the position of the principal meridians it is usually correct, and in many cases where it *appears* not to be so, it is often due to some faulty detail of manipulation, such, for example, as an oblique position of the client's head at the time of taking the reading.

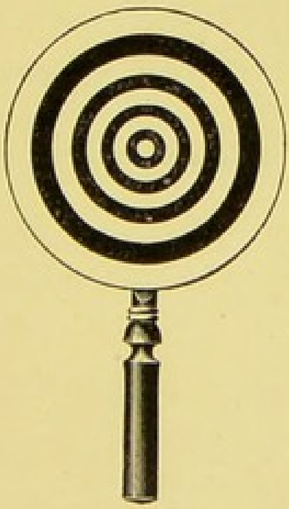


Fig. 81.
Placido's Disc.

A quick method of obtaining information objectively upon the condition of corneal curvature is to employ the disc of Placido.

It shows, by reflection from the surface of the cornea, whether the curvature is equal in the various meridians, and roughly gives an *idea* of the amount, character and position of the astigmatism when such is present. Other objective tests are made for pupillary reactions, hemianopsia, angle of squint, simulated amblyopia and muscular paralysis.

Summary :—

(*a*) An outward inspection of the eyes is always advisable.

(*b*) Naked vision should be taken (eyes separately and together).

(*c*) In the case of children, deaf people, etc., chiefly objective methods are used.

(*d*) If astigmatism is indicated, the ophthalmometer is useful.

Chapter XXVI.

INSTRUMENTS EMPLOYED.

TO apply the principles laid down in the last chapter it is essential that we have a knowledge of the capabilities and limitations of the instruments employed. In order to accurately diagnose optical defects the instruments must be optically correct, and constructed according to an accepted standard. Careful examination on both points is therefore necessary before using them. We will first consider that *sine qua non* of the optician, the case of trial lenses. Without exaggeration we may describe this as the *most important item* in the outfit of instruments, for it is a guide and referee after all other tests are completed, as well as a help in the initial stages, so that the necessity for a high quality of trial lenses cannot be over estimated. The case itself should be stout, well made, neatly fitted and of good appearance, as nothing in an optician's outfit looks more sordid and mean than a shabby and dilapidated trial case. Clients form impressions of an optician's skill from the appearance of his apparatus, and obviously in this connection the trial case needs to be smart looking and well equipped.

Cases are variously arranged, some have the lenses placed in grooves fixed in the body of the case itself, others have them in loose removable trays, and a third kind in sliding drawers. The tray system seems the best, because any time when necessary the tray or trays can be removed for convenience of use. Moreover, if they are made with open bottoms, dust and debris drop through into the tray beneath, instead of remaining in the lens compartment, and thus the cleaning of the latter is easier, and not so frequently needed.

The case may be *velvet lined*, so that neither the lenses nor their rims come in contact with the hard wood, and grooves must be adapted in width to the lenses carried, so that in transit from place to place the lenses may not rattle or shake out. The numbers should be neatly stamped in clear figures at the edges of the grooves, and the case should contain spaces for trial frames, discs, retinoscope, and other accessories. When intended solely for use in the testing room, cases fitted with a bevelled plate of glass in the lid are very nice, but for carrying to outside appointments (where weight and portability are important considerations) the ordinary leather covered ones are preferable.

The lenses contained in the case* are, however, what we must chiefly consider, and there must be a complete equipment of all kinds. They should be of standard diameter (1½ in. approx), and mounted in metal rims with joint and screw, so that individual lenses can easily be replaced when damaged. Each rim should have a metal handle attached to save fingering and soiling the glass, and upon it is punched the sign, + or −, and also the *power* of the lens in dioptres. There should be sphericals, in pairs, both plus and minus, from 0·25 D up to 20·00 D. The lowest power advised is 0·25 D, such small refractive differences as 0·12 D are not necessary, nor, for practical purposes, are intervals of 0·33 D required. Sufficient accuracy can be obtained with powers varying by increments of 0·25 D. The lenses should range from 0·25 D to 3·50 D in steps of 0·25; from 3·50 to 8·00 D in steps of 0·50; from 8·00 to 11·00 D in steps of 1·00; and above that to 20·00 D by wider stages viz.:—from 11·00 to 13·00; 13·00 to 16·00; and 16·00 to 20·00 D, or by smaller stages if wished. In the higher numbers, where the difference in refractive power is only the equivalent of a slightly shorter focal length, small differences are not required, and progression of the power is more rapid.

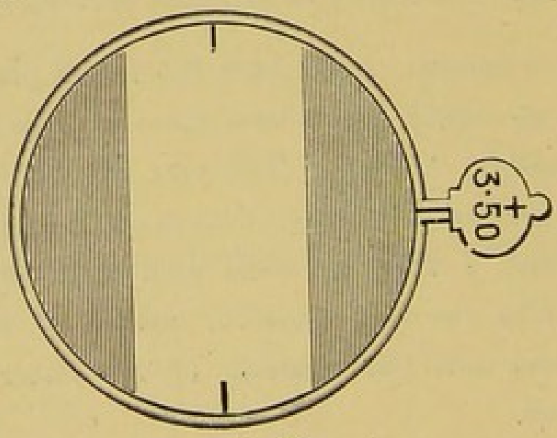


Fig 82.
Etched Cylindrical Test Lens.

The cylindrical lenses should also be in pairs. They will range from 0·25 to 8·00 D, by similar stages to the sphericals above. The two margins parallel to the axis of each lens are usually etched by the sand blast process,

* Trial Cases have been standardised by the National Physical Laboratory and may be obtained with a certificate of accuracy.

so as to resemble ground glass, thus indicating the *direction* of the axis at a glance. In addition a diamond scratch upon the edge of the lens indicates the meridian of the axis when in the frame. The rims, handles, signs, numbers and sizes are similar to those of the sphericals.

The trial case should contain, similarly mounted to the lenses, 1 solid blank disc, 1 pinhole disc, 2 stenopaic discs of different widths of aperture, 1 vivid red, and 1 vivid green glass, 1 Maddox multiple red rod, 1 Maddox double prism, 1 chromatic test, 6 plano smoked glasses Nos. 1 to 6, 6 blue tinted of similar gradation, 1 clear plano glass, 6 pairs of prisms from $\frac{1}{2}^{\Delta}$ to 5^{Δ}, and 5 single prisms from 6^{Δ} to 10^{Δ} inclusive. Two trial frames are necessary; one, to hold one pair of lenses only, light and simply constructed, with straight sides, should be of good steel and nickel plated; the other should be the best and lightest three-cell frame obtainable, fitted with spring clips to hold the lenses, which should be easy of insertion *from below*.

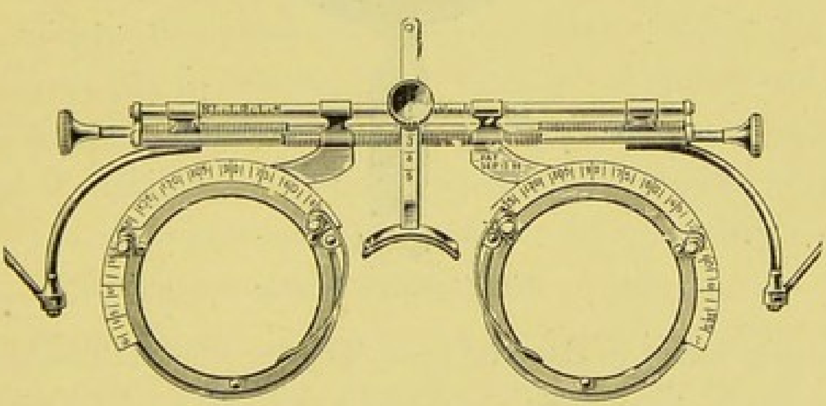


Fig. 83.
Trial Frame.

Attached to the front of this frame there is for each eye a celluloid scale of degrees for indicating the meridian of the axis of a cylinder. The sides are half curl, and adjustable for length. The height and position of the bridge crest is altered by screws, and a right and left hand screw at the ends of the main bar adjusts the cells of the frame to the required pupillary distance. The trial frame must be light, strong, well made, and nickelled, all its adjustments working with smoothness, and the scale of degrees fixed with perfect accuracy to the rims, so that its indication of the meridian of the axis of a cylinder is exact. All the lenses in the trial case should readily fit into the lens holders of this frame, and the clips must hold them lightly, yet firmly, and it should be possible to insert or withdraw them without any undue application of force, and without jerking. All lenses of opposite refraction, but of the same numbers, must perfectly neutralize each other when placed in contact.

Makers of good class test-cases adjust the curvatures of their lenses with this end in view, the principles involved being explained in Chapter XLI. All spherical lenses must be accurately centered, and cylinders so mounted in their rims that the meridian of the axis crosses precisely the geometrical centre of the rim. This is important, and tests should be made to see that all are correct. Other optional accessories are cross-line discs, Scheiner's discs, etc.

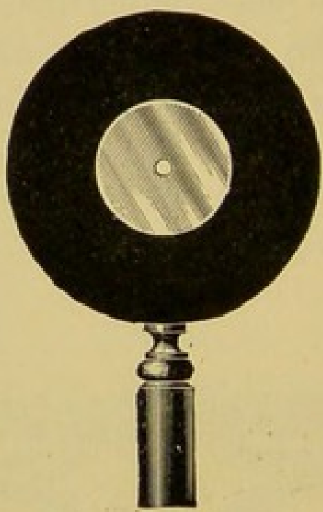


Fig. 84.
Thorington's Mirror.

A place is usually found in the trial case, both for the retinoscopic mirror and the one used for examining the interior of the eye, along with its attendant condensing lens. The retinoscopic mirror may be either plane or concave, but the experience of the leading authorities seems to indicate that a small sized plane mirror with a small perforation is best. If a concave mirror is used it must not be too small. In either case the quality of the mirror should be good, the perforation central and cleanly cut, the mounting neat and substantial, with a long and straight handle. If the concave mirror be of suitable size and proper focus (about 10 inches is best) it will also serve very well as an ophthalmoscope for indirect examination of the fundus. For this a + lens of $2\frac{1}{2}''$ to $3''$ focus, and about $2''$ or $2\frac{1}{4}''$ in diameter should also be provided. It is usual to have special plane and concave mirrors for retinoscopy, so as to avoid wear and tear of the more expensive refraction ophthalmoscope, usually reserved for ophthalmoscopy pure and simple, and mostly for the *direct* examination, for which purpose it is specially adapted. In its most complete and perfect form it should have three mirrors, two of which are concave (one large and one small), and the other plane. Fitted at the back of the instrument is a full range of plus and minus spherical lenses, capable of being placed successively behind the sight hole. The mirrors are on swivels, so that each one of them may be brought into use as required. The large concave and the plain mirror are mounted back-to-back, the small tilted concave mirror being mounted at the other extremity of a revolving carrier, which may be compared, for the sake of illustration, to the double nose piece of a microscope.

This small mirror has a very short focus (about three inches), and sends convergent light into the eye, but the larger concave mirror has a focal length of 8 or 10 inches. The smaller one is usually tilted some 20° to 25°, and is so mounted that the angle of its tilt can be adjusted in any desired direction. It is thus possible to reflect light obliquely into an eye, and yet look straight through the lenses at the back of the perforation. The sight-hole of the instrument should not be more than 3·5 mm. in diameter, which will be a convenient size also for that of the larger mirrors, but the perforation in the small mirror should not be more than 2·5 mm., because in the use of this the central portion is the working part, and if the opening be large the mirror will be less effective. In all instances the sight-hole must be of smaller diameter than the pupil of the eye undergoing direct examination. The lenses at the back of the ophthalmoscope should be easily manipulated, correctly centered, and readily accessible for cleaning or replacement. They should be 6 mm. in diameter.

The Morton ophthalmoscope embodies all the features essential in a good and reliable instrument. It is sent out fitted with handle, complete in a case, along with a suitable condensing lens, and the series of lenses provided at the back of this instrument is very complete.

Other instruments employed in the testing room are the ophthalmometer (Chap. XXXVI.), the phorometer (Chap. XXXVII.), the perimeter (Chap. XXXVIII.)

Minor instruments employed in the testing room are the graduated measure for ascertaining the nearest point of distinct vision, the disc of Placido for revealing corneal astigmatism, Snellen's red and green letter test for binocular vision at a distance, and the reading bar for a similar test at the reading place. In the former, known as the FRIEND test, the client looks at transparent letters of alternate dark green and red glass, when he is himself provided with *spectacles* made from the *same kind of glass* as the letters. With the red glass he reads only the red letters, RED, and with the green glass he reads only the green ones, FIN. So that if he reads both at the same time he has binocular vision, each eye seeing only its own (corresponding) colour. The red and green glasses employed should be of such shades as will most completely neutralize each other. The bar test, which is merely a convenient arrangement of Cuignet's method, is illustrated below, Fig. 85. Accessory apparatus used in the practice of retinoscopy will be described in Chapter XXXV.

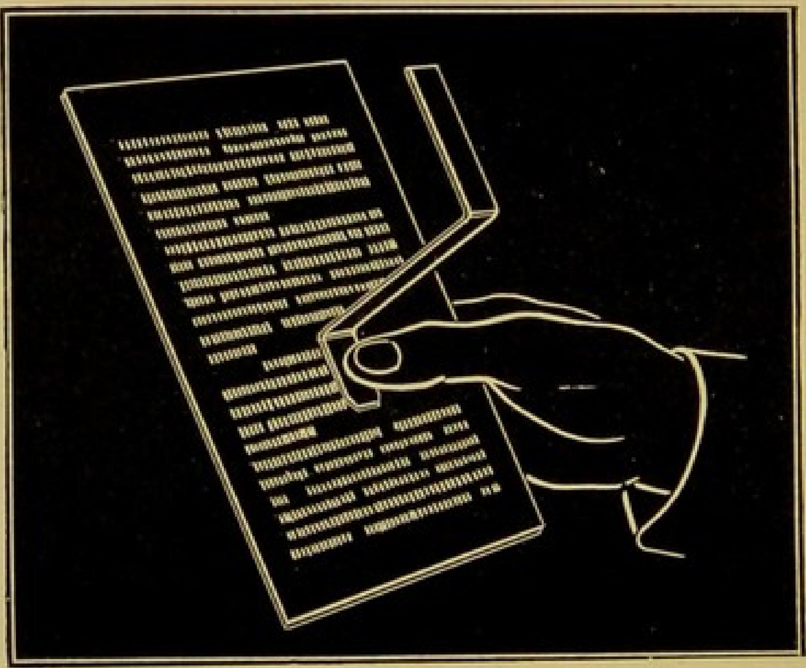


Fig. 85.
Priestley Smith's Bar Test (after Maddox).
By permission of Messrs. John Wright & Co.

Summary :—

(*a*) The trial case should be complete, of first quality, and of good appearance.
(*b*) The trial frame should be light, strong, convenient and adjustable.
(*c*) The retinoscopic plane mirror should be small and have a small sight hole.
(*d*) A concave mirror should be larger and may have a larger sight hole.
(*e*) A complete ophthalmoscope carries three mirrors and a set of lenses.
(*f*) All instruments should be carefully tested before acceptance.

CHAPTER XXVII.

ROUTINE OF THE TESTS.

IN the successful conduct of the business of an optician, as well as for the correctness of the work accomplished, a great deal depends upon routine. The order of the tests employed should be evidence of the methodical utilization of technical knowledge applied scientifically to the facts presented. Clients perceive instinctively, from the manner and methods of the optician, whether he realizes precisely what he is about, and nothing is more fatal to ultimate success than the absence of this conviction.

In dealing with ordinary cases the client should first be comfortably seated, and the head-dress should be removed before testing. The position of the client in the first instance should be such that a good light falls upon his face ; he may conveniently be placed either facing a window, or sideways towards it or some other suitable source of light.

The entry of name and address in the record book can be accomplished without any undue appearance of inquisitiveness, much depending upon the manner in which this is attempted. Age, occupation, etc., are useful data, and with a little diplomacy can be secured. In getting the history of the case stated, the nature of the trouble, its duration, the glasses worn previously and for how long, the presence or absence of pain in and about the eyes, and anything else of importance, should be noted carefully. Whilst all this is being discussed an inspection (rapid and cursory) is made of the general appearance of the eyes and face, anything uncommon or abnormal leading to a more careful external examination of the eyes before any testing of vision is proceeded with. In such an external inspection we should note any malformation, abnormality or disease, the condition and size of the exposed parts of the globes, lids, lashes, lachrymal area and puncta, also the conjunctiva, cornea and sclerotic. Next, the area of the pupils, the colour, condition and action of the irides, and the transparency of the crystalline lens. Then the tension of the globes and the action of the muscles. Finally, the shape of the forehead and nose, and sometimes the condition of the teeth.

Such an examination can be made almost at a glance by a practised observer. For the closer inspection of the cornea, iris, lens, &c., focal illumination is necessary.

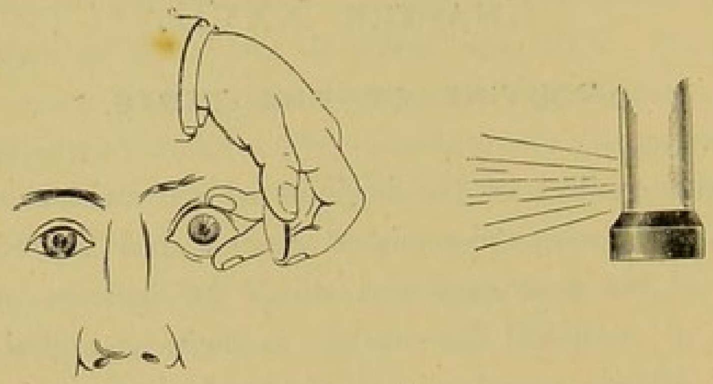


Fig. 86.

Focal Illumination.

This is accomplished by placing the client facing a suitable lamp, the apparatus employed being a spherical condensing lens of 13·00 D. Light from the lamp is concentrated upon the eye, and the lens is so manipulated that the area of illumination passes over the parts to be examined as the lens is moved. To inspect the iris the condenser is moved a little nearer to the client's eyes, and by a further movement in the same direction the lens, its capsule, and the anterior part of the vitreous can be illuminated and inspected. On account of the contraction of the pupil under the stimulus of a powerful light this is almost impossible unless the pupil has been previously dilated. Any conditions of interest or importance are noted, and we proceed to take the visual acuity of each eye separately, in naked vision. It is well to proceed systematically, making it a *rule* to test the R. E. first in all ordinary cases, but in extraordinary cases, where one eye is known or stated to be deficient or weaker than its fellow, to test first the better eye. In all cases, whenever there is vision, both eyes must always be tested. Conclusions should not be drawn from merely testing one only, even in well marked cases of disease, etc., because testing the other eye will help to the formation of a sounder opinon. We occlude the left eye, therefore, according to our rule, and proceed to record the visual acuity of the R. E. by the usual fraction, in which the numerator denotes the distance at which the test is made, and the denominator the number of the line read (which indicates the distance at which it ought to be read.)

The numerator is usually written in ordinary figures, and the denominator in Roman numerals, thus $\frac{6}{\text{VI}}$. If the acuity is greater or less, the difference may be written by the addition to the fraction of an indicating symbol, thus $\frac{6}{\text{VI}-2}$ would mean that two letters in the VI line were miscalled; whilst $\frac{6}{\text{VI}+2}$ would mean that the entire VI line was correctly read, and two additional letters of the next line. This is a very useful plan and is recommended for regular employment. If vision is very defective we employ the pin hole disc, and note any improvement found. In the case of persons of suitable age it is well, after recording the acuity of any eye in distant V., to test the position of the p.p. After this the acuity in near vision is recorded, by finding the smallest type legible, and the furthest distance from the eye at which the same can be read. These observations being recorded, the same tests are to be repeated with the other eye, the R. E. being now covered. Next, we revert to the R. E., and proceed to employ the test lenses at 6 m. in the following order.

(1) Plus sphericals.

(2) Minus sphericals.

(3) Plus cylinders.

(4) Minus cylinders.

the manner of using these, and the principles which are to guide us, will be explained in Chapters XXX and XXXI.

In difficult cases, where satisfactory results are not readily obtainable by the use of test lenses, it is well not to waste time, but to use the ophthalmometer, so as to ascertain whether *corneal* astigmatism is in evidence, and if so, its precise amount, and the direction of the two principal meridians. This ascertained and recorded, the next thing to be done is to inspect the condition of the refracting media, optic disc and fundus by means of the mirror and condensing lens employed for the indirect examination of the interior of the eye. Assuming that no cause is apparent why good results are not obtainable we pass on to the measurement of the refraction by retinoscopy as explained in Chapter XXXV. If desirable the refraction may be estimated by the direct method of examination in addition. From the data obtained we are usually able to calculate with considerable accuracy the lenses necessary, and we proceed to confirm our results subjectively, by putting up the lenses selected before the client's eyes, and modifying them slightly, if required in the interests of comfort or better vision. If the client has reached a presbyopic age it yet remains to measure the amount of deficiency, but this cannot be done until after refraction has been corrected, and so the tests are made with the distance glasses on. Both eyes together are tested, because as accommodation is believed to be exerted equally, in response to a common nerve stimulus from the brain transmitted equally to both eyes, they are considered to be similarly and identically affected. In doubtful cases tests must be made to determine the existence or non-existence of binocular vision, both for distant and near objects, and if there be present any obscure asthenopic symptoms the ocular muscular balance should be tested while the client is wearing the correcting lenses for his defect. In cases of suspected lesion (diseased condition) of the optic nerve or retina it is desirable that the field of vision should be taken, as mentioned in Chapter XXXVIII. Finally, in obscure cases and in certain occupations it may be necessary to test the eyes for colour perception, as described in Chapter XIV.

Summary :—

We first take down the history of the case ; next the outward condition of the eyes is noted ; then we test and record the vision, and the near point of each eye separately (we may also record the acuity when both eyes together are employed). Then we employ the test lenses, each eye separately, and get the best obtainable vision therewith, and record it, along with the p.p. of each eye with the lenses, and also the binocular p.p. (we also may note any lenses added binocularly at this stage), see Chapter XXXI. If **V.** is not satisfactorily corrected thus, we examine the condition of the cornea with the ophthalmometer, and pass on to the ophthalmoscopic examination and retinoscopy. Finally, if required, we test for presbyopia, binocular vision, the muscular balance, the field of vision and colour perception.

CHAPTER XXVIII.

THE PINHOLE, AND WHAT IT TEACHES.

ONE of the most useful adjuncts to the test lenses is the "pinhole disc," or stenopaic pinhole. The former name is preferable, as it is an adequate definition of the character of the article, and does not cause confusion with the other disc, commonly known as the "stenopaic," or more fully the stenopaic slit. As the word "*stenopaic*" means a narrow sight-hole either designation is correct, but, for the purpose of this description we will adhere to the name specified in the headline. It is simply a piece of opaque material pierced by a small circular aperture, the material itself being of little consequence. Hard rubber, metal or celluloid would be suitable so long as it can be perforated without fraying, and other things being equal, the lighter in weight the better. It is well if the disc be made of black material, or otherwise made black by artificial means. The shape of the instrument is in almost all cases circular, and the size being generally identical with that of the trial lenses, the perforated disc is, in all modern trial cases, mounted in one of the ordinary metal rims, exactly as a test lens. Some trial cases are fitted with two, of slightly different sizes of aperture, and while a smaller aperture gives increased definition to the image, yet, as the illumination is decreased, it is doubtful whether there is much advantage in a very small aperture, even in cases where the media are perfectly transparent. A medium size will be found most serviceable and it should have clean-cut edges. The edges of the pinhole are, however, not seen when the aperture is before the eye at the proper distance for the test, as the actual field visible is bounded by the margin of the observing pupil, whatever the size or shape of the pinhole may be (Chapter IX). If the disc is mounted in a rim with handle, and is the same size as the trial lenses themselves, it may, when brought into use, be inserted into the cell of the trial frame before the eye to be tested. This method, whilst easy to the operator, is not to be commended, and the disc is much better placed in the client's own hand, and a little explanation given as to what he is to do with it. If the right eye is being tested, then the pinhole is placed in the right hand, whilst for the left eye the left hand would be the one employed. Manipulated in this way the disc may either be held by its own handle, or placed in a lens holder, the latter for preference.

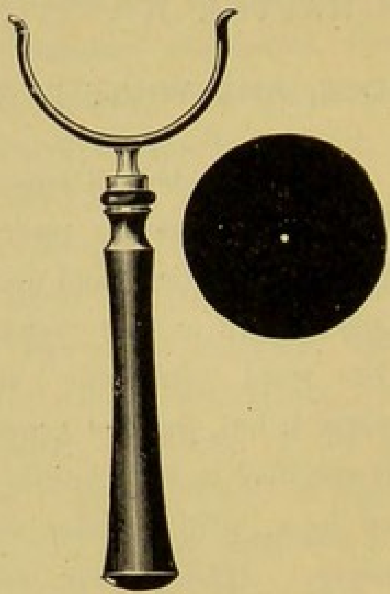


Fig. 87.

Pinhole Disc and Lens Holder.

If the client holds the disc he is able to get the perforation in coincidence with his visual axis immediately, and without annoyance. When placed in the trial frame upon the face, it often happens—no matter how well the trial frame is *apparently* centred—that the aperture is not opposite the centre of the pupil, and the client is unable to use it. If this is the case, rather than allow him to tilt or rotate his head in the endeavour to locate the aperture, it is better to remove the disc from the cell of the trial frame, and employ it in the manner advised above. The cell of the trial frame may be the better position for clients with unsteady hands or head, who otherwise will have considerable difficulty in using it, but in most cases the holder will be preferable.

The visual axis is an imaginary line drawn from the object viewed, through the nodal points of the eye, to the central depression of the macula lutea, which is the area of clearest perception. For practical purposes we may consider this to be the principal axis of the refracting system of the eye; consequently, a small beam of light entering it along this axis reaches the retina without undergoing refraction. We know also that images are formed by small apertures, no matter what the distance of the object, provided that the illumination is sufficient, and that the images of objects at all distances are clearly defined. Here then we have two facts upon which the test is based :—

1st. As the rays of light passing through the aperture are restricted to the direction of the principal axis of the refracting system, they are not affected by the refractive condition of the eye, no matter how ametropic it may be.

2nd. That small apertures produce (with sufficient illumination), clearly defined (inverted) images of objects at all distances.

It is obvious that we have one of the most perfect and useful of all the subjective tests, because, given a sharp and well defined image upon the macula, which we have seen the pinhole produces, if sight is not improved, clearly the fault can only be physiological, and not optical. On the other hand, we can safely say that if **V**. is improved by the pinhole, then there must be present some refractive error, or otherwise an abnormal pupillary condition. It is evident, therefore, that when improved vision results from use of the pinhole, an error of refraction is generally indicated, but if vision is not improved, or is rendered worse, then there is some pathological factor in operation, which is outside the province of the optician. The pinhole has been, not inaptly, described as the optician's finger post. Loss of transparency of the media, of sensibility of the retina, of the transmissive power of the optic nerve, or of the perceptive faculty of the brain, might account for any such failure to appreciate the well defined image projected upon the macula by the pinhole. It is important that the disc be held close, so that light may be confined to the direction of the axis of the eye, and thus employed the test is simple and reliable, often saving considerable worry and loss of time. In all cases where the acuity of vision is of low degree it is wise to try the pinhole, the chief conditions for its successful use being that the illumination of the test object shall be good, and that the aperture itself shall be well centred and of suitable size. Older people will require a pinhole of slightly larger diameter, but it must be remembered in all cases, that the larger the pinhole the worse the definition of the image. Rather than increase the size of the aperture unduly, it is better to bring the client nearer to the test type. A circular aperture is usually employed as a matter of convenience ; theoretically its shape cannot affect the image upon the retina, the field of vision being limited by the margin of the pupil, and not by the aperture used.

If the retina be slightly nearer to the cornea, as in **H**, or slightly further away as in **M**, it will not affect the action of the pinhole, the image produced by the aperture *always being in focus.* Beyond its power of lessening diffusion and diminishing aberration, the pinhole does not appear to give any appreciable increase of acuity in emmetropia ; probably this is largely due to the fact that retinal images are always infinitesimal in size in comparison with the objects viewed, and so, even with the pinhole, no finer details of objects are discernible than with the eye under the most favourable conditions. In high **M**, where there is distension of the retina, due to stretching of the ocular coats, the pinhole does not yield satisfactory results ; this may be due to the fact that, in such an eye, the rods and cones of the retina are more widely separated, and the image obtainable from the use of the pinhole does not impinge upon a sufficient number to excite in an appreciably greater degree the sense of sight. In cataractous conditions and other states wherein the transparency of the refractive media is impaired, the pinhole will not in all probability improve vision. This should be clearly understood. Likewise, if there is an amblyopic condition from any cause, vision will not be improved. On the other hand, in irregular astigmatism and conical cornea the pinhole often improves vision considerably more than can be obtained by lenses. Still, the broad rule holds good, in spite of certain exceptions on both sides, that when **V**. *is* improved by the pinhole, we can generally look for, and obtain, **V**. *better still* by the aid of lenses, and therefore we should not be content with vision merely as good as that so produced, but should look for something better.

In cases of corneal nebulæ we may occasionally get an improvement by lenses when the pinhole does not reveal any, possibly on account of the feebler retinal illumination.

Reference has been made in Chapter IX to certain entoptic phenomena observable by the specific use of pinhole apertures, under certain conditions. In sight-testing these phenomena are not likely to cause any appreciable interference with vision, except possibly in certain forms of cataract, as the ordinary illumination of test cards is hardly sufficient to produce, in an ordinary room, the more obscure entoptic phenomena. It is only requisite to use the pinhole when vision is markedly defective ; if approaching normal, its employment is unnecessary, nor is it called for in ordinary cases of strabismus with consequent amblyopia. Nothing whatever is gained by employing lenses with the pinhole. Certain clients of nervous temperament are bad subjects for its use, and frequently considerable tact is necessary to obtain satisfactory results. The pinhole is usually employed at 6 metres in testing the visual condition, and it may be employed in near **V.**, provided accommodation is good, but if this *be defective* it must be supplemented by a plus spherical lens of suitable power. Its use in this way, however, is seldom necessary.

Summary :—

(*a*) The pinhole should be placed in the client's own hand.

(*b*) Subnormal vision is improved by it in cases of refractive error.

(*c*) If **V.** be not improved there are other causes operating.

(*d*) The pinhole must be held close to the eye, and well centred.

(*e*) The aperture must be small, and illumination of object good.

(*f*) We expect to obtain, by lenses, better vision than by pinhole.

(*g*) In some cases we get results contradictory to indications, but such are exceptional.

Chapter XXIX.

TEST TYPES AND THEIR MEANING.

THE apparent size of any object which we look at depends upon the size of the visual angle, which may be defined as the angle formed at the first nodal point of the eye by two imaginary lines from opposite extremities of the object. As the two lines meet at the nodal point, if we produce them, backwards, beyond the object, they will diverge so that any object subtending the same angle must be larger in size the further it is placed away from the eye, and the increase in linear size is directly proportionate to the increased distance. An object clearly visible at 20 feet would require to be three times the size to be visible at 60 feet, and conversely, the further objects of the *same* size are removed from the eye, the smaller is the visual angle which they subtend. Subtending the same angle, objects at very different distances, and of very different sizes, form upon the retina images of the same size ; and conversely, the *same* object, if at different distances, would form images of different sizes, because the angle subtended would vary with each variation of distance.

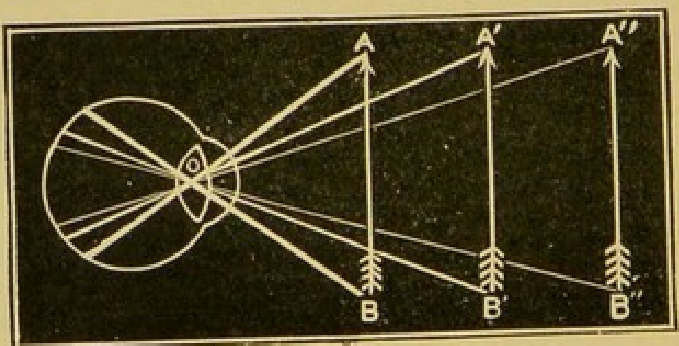


Fig. 88.
Illustration of Visual Angle.
Three objects of same size, A B, A'B', A''B'', form three different angles at the 'nodal point' because they are at different distances from that point.

The larger the image, the nearer is the object, and the larger its visual angle ; the further away the object, the smaller the image. The size of the image upon the retina is in the same proportion to the size of the object as the distance of the second nodal point from the retina is to the distance of the object from the first nodal point. A single nodal point, for purposes of calculation, may be assumed to be 15 m.m. from the retina.

The limit of perception is reached when the visual angle subtended by an object becomes too small to produce a retinal image of such a size as to enable the object to be recognised, and the smallest angle which an object can subtend, and still be distinctly visible, is the measure of the maximum acuteness of vision. It is evident, from what has been said with regard to the proportion existing between size and distance, that the acuteness of vision is estimated from these two factors. Snellen determined experimentally that the average acuteness of vision in normal cases is measured by objects subtending an angle of 5′, and on this principle he based the construction of his test letters. He found that the smallest separate part of an object, to be distinguishable from the entire mass of the object, must be not less than 0·20 of the whole, so that individual parts of an object must subtend an angle of not less than 1′. Under such an hypothesis, two stars separated by a distance which subtends an angle of less than 1 minute at the nodal point of the eye, would appear as one. Upon this system his test types are constructed; each separate part of each letter is $\frac{1}{5}$ of the whole, and the openings between the parts are of similar size, a letter of block shape being divisible both ways into 5 parts, each subtending an angle of 1′.

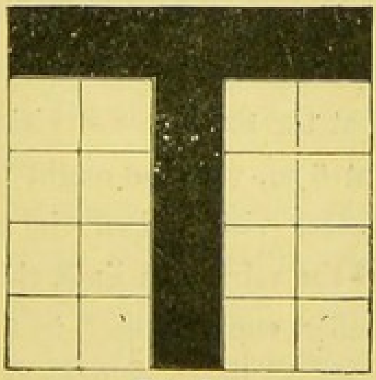


Fig. 89.

The size of the letters for ordinary test types at different distances is ascertained by mathematical calculation, the relation of the size to the distance being expressed approximately by the tangent of an angle of 5′, viz.:—·001454. To calculate the size of a letter required to subtend an angle of 5′ at a given distance, we multiply the distance in mm. by ·001454, which gives the size of the letter in m.m. To be more accurate the tangent of the angle is really better expressed, in this case, as *twice* the tangent of an angle of *one half of* 5′ ($2\frac{1}{2}'$), but for practical purposes the factor mentioned is sufficiently correct. Other more severe tests have been drawn up, on similar lines, to subtend an angle of 4′ instead of 5′, as some authorities consider that the latter standard is not sufficiently high, for many people have an acuity greater than that measured by an angle of 5′. Some letters are easier read than others of the same size, O & L for instance, the former being legible under an angle of 3′ and the latter under an angle of 2′, hence they are less useful. It is easy to calculate from the particulars given, the size of any letter at any distance either for 5′ or 4′, the latter being of course $\frac{4}{5}$ of the former. From the size of the letter we can also calculate the size of its retinal image; for an angle of 4′ the image of each *part* of a test letter will be ·00349 mm. which is rather more than the diameter of a retinal cone in the region of the macula (from ·0033 to ·0036 mm.), this relation between the highest limit of visual acuity and the physiological structure of the retina being very interesting (Chap. VIII.) A very useful graduation consists of types constructed for 60, 36, 24, 18, 12, 9, 6, 5, 4, and 3 m. The cards are marked with the standard distances necessary to give an angle of 5′ for each letter in the same line, so that, knowing the standard distance, and having the standard object, our test is complete. The test types must be hung in a good light, and at a distance of 6 m. Vision is recorded by the formula $V. = \frac{d}{D}$, where V. = the acuteness of vision, and d. = the distance at which the test is made, whilst D. = the distance at which the type actually read *should be read* to subtend an angle of 5′. Thus $V. = \frac{6}{60}$, means that the acuteness of vision is only $\frac{1}{10}$th of normal, for the client can only see at 6 m. what he ought to see at 60 m. In average cases we should get better vision than the standard $\frac{6}{6}$, but age of the person, and condition of the refraction limit this. Vision in young people, and in low degrees of defect ought to be $\frac{6}{5}$ to $\frac{6}{4}$. In high degrees of optical defect a lower acuity may be taken as normal at any age. After fifty we may take $\frac{6}{6}$ as normal vision; after sixty-five we may perhaps accept $\frac{6}{9}$; and after seventy-five possibly $\frac{6}{12}$. For determining the acuity in near V. we use smaller types constructed on Snellen's principle, noting the smallest type readable, and the *greatest distance* from the eye at which it is legible.

Jaeger's test types, for the same purpose, do not subtend any fixed angle, but are merely ordinary printers' types, arranged in a convenient series of sizes, and are preferred by some because the type is more like that of newspapers and books, with which clients are familiar; the idea being that tests made with these are more reliable, because of a more natural and familiar character. The test types for near V., arranged by Oliver, of Philadelphia, are excellent in principle, and thoroughly scientific. As the words do not form ordinary sentences, there is no possibility of conjecture coming into play in the use of them. Hand types common in England are Cowell's, and the Moorfield's Hospital Selections.

From the manner in which clients read the letters, a good idea can often be formed of the nature of the defect. Hyperopes (absolute) will read along as far as they possibly can, with a *steadily decreasing accuracy* in the more severe stages of the test, until they reach the limit of their power and collapse, with the observation that they cannot make out any other letters.

Where the H. is facultative V. (by help of the accommodation) is frequently *above normal*, and the type will be read perfectly. In myopia normal vision is not possible, and myopes have bad distant vision in direct relation to the amount of the defect. As a rule they do not read much of the type at 6 m. and that not very well, and frequently the distance has to be considerably shortened to enable even No. 60 type to be deciphered. Astigmatic persons are often recognised by the confidence they express in their visual powers, and which they generally fail to justify. Letters are named by such without hesitation, but in many cases wrongly, being mistaken for *similar* letters of the alphabet. In marked cases of astigmatism, and in the higher compound defects, vision is usually very defective, especially in compound myopic and mixed astigmatism. In cases of spasm of accommodation distant vision fluctuates more or less from time to time, and a line of letters legible one moment may be illegible the next, and vice versa.

The hand-type is used to measure the accommodation as well as the visual acuity. It serves in H. to show whether the defect is still latent to any considerable extent (evidenced by the reading of fine type not being comfortable). The p.p. shows the amplitude of accommodation, which *should* agree with the age ; if with the distant glasses on it *does not*, then there is a presumption of latent H., equal to the difference between the p.p. as it is, and as it should be, (reckoned in D's of amplitude). In M. the p.r. is a rough guide to the amount of M. ; and with the distance glasses on the p.p. will show the amplitude of accommodation, and indicate any need for *modified* glasses for near V. In presbyopia the types are used to determine the condition, and the correction required, after the refraction has been dealt with and corrected for the distant type.

In near vision, in average cases, the eyes possess a greater acuity that they do at 6 m., probably due to the better illumination obtainable from near type, and also in some degree to the better definition, the aberration of the eyes being less when the pupils are smaller during accommodation and convergence. We naturally *expect* therefore to find **V**. better near to than further away. We have already seen that the distance of the object from the nodal point of the eye regulates the size of retinal image, and this explains why some hyperopes of high degree hold their work very near to the eyes. They cannot accommodate for such a point, nor do they get clear vision, but they obtain a larger blurred retinal image, and have learned to prefer size to clearness, as the easier means of satisfying their visual needs. Such persons are, at times, wrongly considered myopic, an error which the optician should carefully guard against.

Some refractionists prefer white letters on a black ground for testing, and generally a higher acuity can be obtained with these, the effect of irradiation causing the letters to appear larger, while the small retinal areas stimulated are better for discernment than in the ordinary style, where the stimulated areas correspond to the white ground. Various other types have also been constructed, notably Landolt's which is a circle broken by a gap of the same thickness as the ring itself. This figure has the dimensions of Snellen's letters, and the acuity is tested by naming the position of the gap. It is superior as a scientific test, but there is a difficulty in obtaining satisfactory answers from the average ametrope, a difficulty which also exists with the type composed of the block letter **E** in various positions. The Ettles' chart of a figure of Punch is well arranged for testing the acuity of children, and various others illustrating common objects—generally badly designed for the purpose—can be obtained. These are intended also for illiterates, as are a number of charts consisting of dots and symbols.

Summary :—

(*a*) The standard test is a definite sized object at a fixed distance.

(*b*) The size of the object is determined by its distance from the nodal point.

(*c*) The acuity of vision is measured by Snellen's type.

(*d*) The smaller the angle subtended, the greater is the visual acuity.

(*e*) The limit of acuity is an angle of 4′ to 5′.

(*f*) In near **V**. acuity is usually greater than at a distance.

(*g*) Near types measure accommodation as well as acuity of **V**.

CHAPTER XXX.

RECOGNITION OF REFRACTIVE ERROR.

IT is in the ability to correctly diagnose and measure errors of refraction that the skill of the refractionist is exemplified, and by the manner in which he works his ability as an expert is judged. In considering the nature and estimation of visual defects we must understand clearly the optical condition of the defective eye, even to noting, wherever possible, the condition of the pupil, because this influences the size of the circles of confusion, and so alters the definition of the retinal image with the same error of refraction. The reason why myopes see better with increasing age is because the pupils get smaller, and again, in near vision, the myope with small pupils has an advantage, just as when viewing distant objects the hyperope sees much more clearly when the pupils are small. In Chapter XIX the various defects are explained, Chapter IX also having a reference to astigmatism, which may be simple, as there mentioned, compound or mixed.

Astigmatism may exist in eyes otherwise emmetropic, it is then simple ; it may be an addition to a condition of deficient or excessive refractive power in the eye as a whole, when the term compound astigmatism is applicable. In the other variety the refraction is of entirely opposite character in the two principal meridians, being too great in the one and insufficient in the other, with a varying amount in all the intermediate meridians ; such a condition is termed mixed astigmatism. Commencing with an eye having precisely the correct amount of refraction required, we find (other conditions being favourable), that V. at 6 metres is fully up to normal, with due allowance for the advent of old age, thus proving the existence of a sharp focus at the retina for objects representing the limit of normal perception. We also find that even a very weak plus sph. lens makes V. worse, by creating a condition of myopia, and diminishing through consequent retinal diffusion, the sharpness of the image received by the eye. The p.p. is also at the near point indicated by the age in Donder's Table, which, although not always exact in every instance, is yet wonderfully correct in the majority of cases.

We may now exhibit the fan of radiating lines, and if all are declared to be equally black and distinct, we may claim to have *proved* the condition of emmetropia.

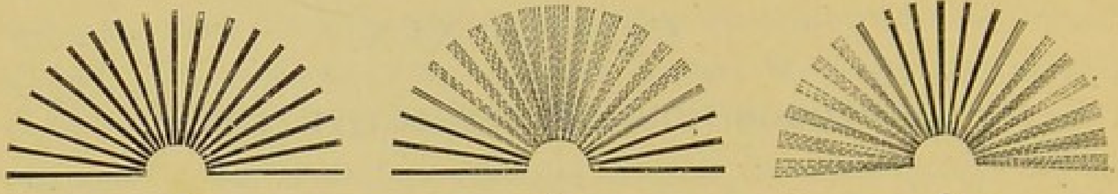


Fig. 90.

Astigmatic Fan as seen (1) In Emm. (2) In simple hyperopic astigmatism with faulty horizontal meridian. (3) In simple myopic astigmatism with faulty vertical meridian.

This, it will be noticed, we have done by a process of exclusion, which we may summarize as follows :—

(1) Vision at 6 m. being normal *excludes* myopia and absolute hyperopia.

(2) A weak plus sph. lens making V. worse *excludes* the presence of manifest H.

(3) The p.p. being at the normal place presumes the *absence* of latent H. of any appreciable amount ; although, given a large amplitude of accommodation, this would not be regarded as absolute proof.

(4) All the radiating lines being equally clear and black at the same time, *excludes* astigmatism.

In considering the probability of there being latent H., regard should be given to any asthenopia complained of, and it must be remembered that, binocularly, pairs of weak plus spherical lenses will often be accepted with benefit, when monocularly they are refused, thus proving H. to exist in cases where previously Emm. might be considered probable. The reason for this lies in the close relation existing between accommodation and convergence. It is found, in these cases, that accommodation is easier to repress when both eyes are in use together, because, owing to the necessity of maintaining binocular vision, an eye cannot accommodate so forcibly as it can when the other eye is covered. When in that condition there is also no need to restrain convergence, whereas otherwise there is. Consequently a little tonic convergence coming into play accommodation follows involuntarily, and the eye seems emmetropic, when it really is not so. This same modifying effect of monocular vision likewise affects most persons who are astigmatic, hyperopic or myopic during youth, so that frequently young hyperopes, when tested, will seem to be a little less hyperopic than is really the case, and myopes will, on the other hand, appear to be somewhat more myopic than they really are. The proper precaution with *all* under 30 years of age is to add to every correction fitted monocularly at 6 m., the strongest pair of plus spherical lenses (to both eyes simultaneously) that does not make vision *worse*.

We must now consider the case of an eye with a deficiency of refractive power. If we examine the visual acuity of such an eye at 6 m., we may find vision either normal or sub-normal; if normal, it can only be so by an exertion of accommodation. The fact that vision is up to standard proves merely the presence of a focus at the retina, but it does not indicate how that focus is obtained. In the other condition, where vision is sub-normal, there is no sharp focus at the retina, because accommodation cannot be exerted sufficiently to adequately increase the refraction of the eye. As vision is usually subnormal both in myopia and astigmatism, we have to take steps to exclude both these in making our diagnosis certain. To revert to the instance where V. *is* normal at 6 m. If a weak plus spherical lens does *not* make V. worse, then a condition of hyperopia is *proved*. There is no condition other than this in which a plus lens is not immediately rejected. The fact that the sight is *as good* with such a lens as without it, establishes beyond all doubt the necessity for it, and at the same time excludes emmetropia, just as the possession of normal vision at the outset excluded myopia. The theoretical correction in such a case is the strongest plus spherical lens that does not make vision worse. In those cases where vision is sub-normal the same general rule holds good, viz., that suitable plus lenses do not make V. worse (thus again excluding myopia), and they do make it better (thus excluding simple astigmatism), so that if sub-normal V. is not made worse by plus sphericals, but on the contrary *is improved*, H. is again determined, and the correction becomes, as before, the strongest plus spherical giving normal (or the best obtainable) vision. In H., without lenses the p.p. will usually be found further away than the normal place for the age. This fact comes under discussion in Chap. XXXIV.

We will now consider the case of an eye with an excess of refractive power over what is required for the focussing of parallel rays of light. Such an eye is myopic, and its focus lies somewhere in the vitreous—in front of the retina. Evidently there will be circles of diffusion upon the retina, and the exertion of accommodation in such a condition as this, by increasing the refraction, renders it worse, and makes the eye more myopic; hence a myope gains *no* advantage in distant V. by accommodating.

Owing to diffusion at the retina, the distant V. in myopia is never normal, and, as plus lenses increase the eye's refraction, it is evident that they must increase the myopia, and consequently the retinal diffusion, and thereby decrease, concurrently, the visual acuity. Myopia is determined if vision is sub-normal, and a plus spherical lens makes it worse, whilst a minus spherical lens distinctly improves the sight, by rendering legible a line or lines of letters not legible before. Confirmation is found if the p.p. is *within* the normal place for the age, and the p.r. at a distance *within infinity*. In simple myopia the correction is the *weakest* minus spherical that gives normal V. With this lens before the eye all the bars of the astigmatic fan will appear equally black and distinct, proving the absence of astigmatism.

For recognition of the presence of astigmatism the essential thing to remember is that in this defect the refraction of the eye *differs* in every meridian, and consequently it is impossible for all the radiating lines of the astigmatic fan to be in focus upon the retina at the same time. The fact that some of these lines are seen more distinctly than others is diagnostic of astigmatism, In simple astigmatism of the variety hyperopic, one principal meridian is Emm., and the other H. and all the intermediate meridians are H. in varying degrees. In simple myopic astigmatism one principal meridian is M. and the other Emm., and all the intermediate meridians are M. in varying degrees. Vision, except in *very low* degrees, is generally subnormal, and neither plus *nor* minus spherical lenses afford decided improvement in simple astigmatism, but in compound astigmatism one or the other will possibly afford improvement, within certain limits marked by the amount of error in the meridian of least defect.

Simple astigmatism is recognised, when V. is sub-normal, by neither plus nor minus lenses affording any real improvement, some bars of the fan looking blacker than others, and V. being so improved by a plus or minus cylinder that all the bars are seen equally black. In compound astigmatism a spherical lens improves the sight, and the addition of a plus or minus cylinder *improves it still further*. The selection of these lenses will be dealt with in the next chapter.

Mixed astigmatism is rather more troublesome to determine, because both principal meridians are defective, and their defects are of opposite character. In these cases usually no bars on the astigmatic fan are seen distinctly, though this is not always so. It is determined when **V**. is improved by plus and minus powers in any two opposite meridians. The best method is to put before the eye a plus sph. lens with a higher minus cylinder; say, for example a + 2·00 D sph. ○ − 4·00 D cyl. axis horizontal, and rotate the cylinder. If **V**. is *improved* in any position, then the necessity for both plus and minus refractive powers is established, and mixed astigmatism is proved. In this defect vision is always subnormal, and spherical lenses do not afford satisfactory improvement, nor do plus cylinders. Care is required, however, to avoid fitting with minus cylinders, and thereby making such eyes hyperopic instead of emmetropic. Such a mistake would be revealed by the position of the p.p. (Chapter XXXIII). The safeguards against the wrong use of minus cylinders will be discussed in the next chapter.

Mixed **As**., is simplified considerably by correcting one meridian first, either by the stenopaic or the fogging system. The correction of one principal meridian immediately reduces the refractive condition to one of simple astigmatism.

Summary :—

(*a*) Normal vision does not prove the absence of **H**.

(*b*) A plus lens is immediately rejected in all except hyperopic conditions.

(*c*) In **M**. normal distant **V**., without glasses, is not possible.

(*d*) Minus lenses are *entirely wrong* in any condition except a myopic one.

(*e*) Spherical lenses being rejected, cylindrical lenses may improve **V**.

(*f*) If sphericals are accepted, cylinders may be added, if indicated by tests, and if, *on trial*, they improve the sight more than sphericals alone.

CHAPTER XXXI.

MANIPULATION OF TEST LENSES.

IN the manner of handling the test lenses there is a considerable amount of scope for individuality of method, each operator having his own particular style. It may, however, be safely laid down as an axiom for the guidance of all, that speed in testing should be aimed at in every case, the desired result being attained in the smallest possible number of moves. Further, all changes of lenses should be made in recognised order, and those rejected should be instantly reinstated in their own places in the trial case, and not, as is sometimes done, placed in a heap to be sorted afterwards. Lenses should be manipulated by their handles only, so as to avoid fingering, and any necessary wiping should be done with an old soft silk handkerchief, in the gentlest manner possible. It is imperative that test lenses be kept in a perfect condition, and therefore it is desirable that those used for testing should not be used for neutralizing, because of abrasion, a separate set being kept solely for that purpose. The first thing to do in testing with the types is to adjust the trial frame to the client's face, giving some short explanation of its purpose. It should be adjusted for efficiency and comfort, and must never be irksome or painful to the client.

The sides must be adjusted to give security without undue tension upon the ears, or pressure upon the nose. The rims must be well centered, each cell being adjusted individually in the case of faces not symmetrical in the height of eyes or ears, or in the distance of the eyes from the median line of the nose. The bridge should be so adjusted that the cells of the trial frame are at a reasonable distance from the client's eyes, the trial lenses corresponding as nearly as possible with the position in which the spectacle lenses will afterwards be worn. The next proceeding is to occlude one eye with the blank disc, and unless there is some special reason to the contrary, it is better in every case to occlude the left eye first. The right eye, then, is tested without lenses, and its visual acuity recorded. If **V.** is normal, or only slightly sub-normal, it is well to immediately take the p.p., but if **V.** is markedly defective we apply the pin hole in the manner already described in Chap. XXVIII., and also take the acuity in near vision, as mentioned in Chap. XXIX. The next thing, supposing that the case is within the province of the optician, is to proceed with the application of lenses. If **V**. is normal, ($\frac{6}{\text{VI}}$), we do not expect to find any very high degree of defect, and it would be folly to put up any strong lens. We commence in all cases *with plus sphericals*, so as to avoid excitation of accommodation, our object being in all subjective testing to repress this as fully as possible. In the event of normal **V**., we should commence with a weak plus sph., say 0·50 D, and if accepted, we should insert this lens into the cell of the trial frame, then, taking two other lenses in the right and left hands respectively, viz : plus 1·00 D in the right, and plus 0·50 D in the left, should *hold them* successively in front of the lens already in situ. If the plus 1·00 D is accepted we may place this in the front cell of the trial frame, now holding the plus 0·50 D in front of both. We should *not* insert this, if accepted, but try the effect of another plus 1·00 D and if this is also accepted, substitute plus 2·00 D for the front lens in the frame, and so on ; but if this plus 1·00 D is rejected, we must try instead the plus 0·50 D, and if accepted, place plus 1·50 D in the front cell, in place of the plus lens already there, and then try if an additional plus 0·25 D can be added. Similarly with the other eye. If in the first instance vision is decidedly sub-normal, it would be a waste of time to start with such a weak lens as plus 0·50 D, and changes should be made in stages of at least 1·00 D, so that a marked effect either way is produced, and smaller changes made as the final adjustment is approached. In all cases where *plus* spherical lenses are accepted in testing we find the *strongest* lens that gives the best obtainable sight, although this may be subject in some cases to subsequent slight modification. If plus sph. lenses are rejected, minus sphericals are next tried, but they are not given unless they produce *marked improvement* in **V**.

The object in testing for myopia is to find the *weakest possible minus* spherical lens that will give the best sight obtainable, and there is only one way to select that particular lens. We exclude any stronger one because it *does not* decidedly improve **V**., and any weaker one because it makes vision worse ; so that, by a process of elimination, the correct lens is arrived at. Supposing, however, that *both* plus and minus sph. lenses are rejected, as not improving the sight in sub-normal vision, we then suspect astigmatism, and if this is confirmed by some of the lines on an astigmatic fan being seen clearer or blacker than others, we observe the direction of the line seen clearest or blackest, and making a mental note of its meridian, we proceed to apply plus cylindrical lenses, *with axes at right angles to the clearest line*, that is to say, corresponding in direction with the most blurred one, and proceed to select the strongest plus cylinder giving the best obtainable sight *with* Snellen's *letters*, and also making all the lines of the fan appear equally black (Fig. 90). If plus cylinders do *not* improve the sight, then minus cylinders are tried, with their axes in the same position, and the weakest is selected that gives the best obtainable vision and equalizes the fan lines. If, instead of the astigmatic fan, any chart is used with lines in a circular direction in place of radiating bars, the blurred *part* of this chart will be at right angles to the blurred part of the fan, on account of the changed position of the lines. Consequently, with such, the axis of the cylinder is placed across the blurred portion, *and parallel to the lines blurred*.

In fitting cylinders the original position for the axis may not be the right one, and a little rotation may result in an improvement in **V**. If so, the best position is carefully located, and taken as correct. After fitting a cylinder we must always try to add on, both monocularly and binocularly, as much *plus* spherical power as possible without making vision worse; or if necessary, minus spherical power may be added (subject to the usual restrictions), if it definitely *improves the sight*. The addition of plus spherical power monocularly and binocularly is most useful as a safeguard against the wrong fitting of minus cyls, and should never be forgotten in testing. The rules for cylinders are mainly the same as for sphericals; that is to say, the strongest plus or weakest minus giving best results. If in doubt about two lenses, we select the weaker one, and in obscure cases endeavour rather to under than over correct. Cylinders should never be fitted unless they afford *improved vision*. In astigmatism cylindrical lenses do not always give normal sight at once, but they do generally effect a very considerable improvement.

Compound cases are suspected when, although spherical lenses are accepted, as affording better **V**., the sight remains nevertheless subnormal, and all the lines on the astigmatic fan are *not* equally black. One way to proceed in these cases is to correct first the meridian of *least* defect, by leaving in the trial frame the *weakest* spherical lens (whether plus or minus) giving the best obtainable sight, and then fitting cylinders as before. In this way results are obtained with congeneric combinations which are simpler to reckon throughout than contrageneric ones. When sphericals have been accepted cylinders should not be added, unless they manifestly *improve* the sight. Mixed astigmatism can be corrected by a plus spherical combined with a higher minus cylinder, or by a minus spherical combined with a higher plus cylinder. The exact correction is found by making alternate changes of spherical and cylinder, until the best sight is obtained, and all bars are equal, always keeping to the general rule of strongest plus or weakest minus. The adding on, wherever possible, of plus spherical lenses, as described, is very important in all cases of mixed astigmatism.

In high degrees of defect it is not wise to employ weak lenses at the start, and the higher the defect recorded by diminished acuity, the more likely is the need for strong lenses. Myopia, for instance, is never disproved until rather strong minus lenses have been tried. In high degrees of this defect weak sphericals make no appreciable improvement, and so are useless for test purposes. If vision is less than $\frac{6}{\mathrm{LX}}$, and plus lenses make it worse, it will be expedient to try $-3{\cdot}00$, at least, then $-5{\cdot}00$, $-8{\cdot}00$, and so on, until some noticeable effect is gained. The endeavour throughout should be to make as few insertions of different lenses into the trial frame as possible, and, to this end, much may be done by dextrously *holding* supplementary lenses in front of the eyes. In selecting cylinders great exactness may be obtained by holding weak cylinders in front of those already fitted, first with their axes parallel, and then at right angles to those in the original combination.

Such additional cylinders may be either plus *or* minus, and 0·50 or 0·25 as required. Quickness in mental appreciation of the resultant lens comes from practice and facility in transposing. The rapid employment of first a plus, and then a minus cylinder, in this way, is but a matter of a few seconds, and the gain in results is often very remarkable. In some young people with very active accommodation, astigmatism is difficult to test, and such are often best corrected by first fitting a minus cylinder and then adding on plus sph. power as fully as possible after the astigmatism is thus disposed of.

An excellent device for checking an astigmatic correction is Jackson's "crossed cylinder," which consists, as its name indicates, of a lens with equal and opposite weak cylinders, $-{\cdot}25$ D and $+{\cdot}25$ D or $-{\cdot}50$ D and $+{\cdot}50$D, with their axes at right angles. These may more readily be obtained as — ·25 D.sph. ⊂ + ·50 D.cyl, or its equivalent + ·25 D.sph. ⊂ – ·50 D.cyl, and similarly for the stronger one. They should be mounted in rings with a straight handle like that of a retinoscope, and the axes of the cyls, with their powers, should be clearly marked upon the glass.

When testing with sphericals much depends upon the predominance of **V** or **H** lines in some letters, as to what lens gives the best result, and often too strong a glass is placed before the eye, so that the cylinder added is then a little too weak, and although good vision may be obtained, there is a possibility of getting somewhat better acuity, and in this the device is particularly useful, because when placed first with, say, the plus axis vertical and the minus horizontal, it alters each meridian of the combination in the frame by ·25 D, increasing the one and diminishing the other. Now, by quickly rotating it before the eye, so that the powers are in opposite meridians from what they were before, it causes a sudden change in power of both meridians, and the client is asked which of the two positions gives the better result, and the lenses of the trial frame are changed accordingly, the axis of the cylinder being rotated a trifle to ascertain if any improvement can be gained by so doing.

Where astigmatism is considerable the stronger crossed cylinder may be used, as it indicates a greater change in the powers, the weaker one being afterwards employed if necessary.

Summary :—

(*a*) Adjust the trial frame carefully, and centre the cells to each eye separately.

(*b*) Make it a rule to test **R. E.** first, in ordinary cases.

(*c*) Always commence every test with *plus* lenses.

(*d*) Let the first lenses be weak if the defect seems slight; stronger if high.

(*e*) *Hold* supplementary lenses before the eyes, in testing.

(*f*) Cylinders will improve the sight if they are needed, and should not be given unless they do so.

Chapter XXXII.

STENOPAIC TESTING AND THE FOGGING SYSTEM.

BY means of the stenopaic slit it is possible to test subjectively the refraction of the eye in each separate meridian, the disc allowing light to enter in one meridian only.

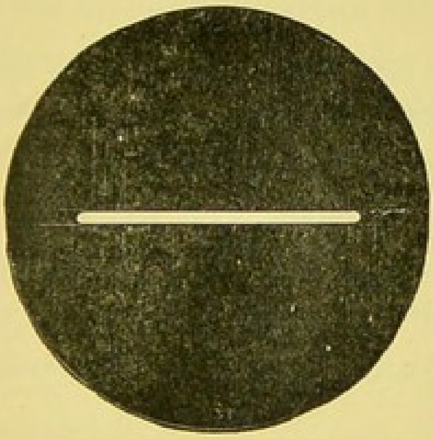


Fig 91.

Stenopaic Disc.

No advantage follows from the use of such a method in cases of simple H. or M. but in testing astigmatism it may be of great value. The advantages claimed for this method of testing are simplicity, ease of manipulation, and rapidity, and as practised by those who have made it a speciality, it is successful; but it has also considerable disadvantages. Theoretically it is an ideal method of correcting astigmatism subjectively, and given an intelligent client, with eyes thoroughly under the influence of a mydriatic, it is excellent.

The stenopaic should be well centred in relation to the pupil in either a horizontal or a vertical position. This is often neglected, and it will be seen that the slit may often coincide exactly with the horizontal meridian of the eye, but not with the vertical, after a rotation of 90°.

Fig. 92 shows this. Now, as it is impossible to centre the slit by observation, we can only judge when it is in the proper position from the pose of the client's head. If he sees through the slit in *both* its positions, without either tilting or rotating his head, then it may be considered well centered.

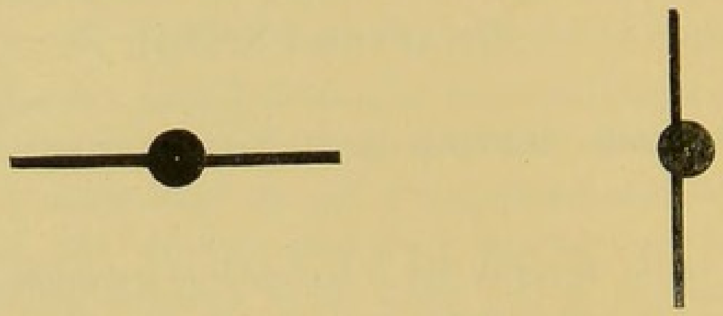


Fig. 92.

The object is to locate the precise direction of the two principal meridians (of highest and lowest refraction), and here, unless care is employed, the manipulation will be troublesome in all cases where accommodation is active. No radiating lines or cylinders are necessary, because, with a spherical lens in conjunction with the stenopaic, the curvature is only active in the direction of the slit, so that under such circumstances it acts like a plano cylinder placed with its axis at right angles to the opening. We employ, *in testing*, merely spherical lenses, and use the Snellen's test type at 6 m.

It is necessary to first put up before the eye that spherical lens, either the *strongest* plus or the *weakest* minus giving roughly the best obtainable sight, and in so doing we repress accommodation. With such a spherical lens we put up the slit, say in a horizontal position, and rotate it until the meridian of best vision is found; then, while in that position, fit the strongest plus, or weakest minus, and again rotate the slit a little either way, so as to *more precisely* locate the best meridian, and again try plus and minus sphericals in the new position; once again we try the effect of a *slight* rotation for improvement of vision, and take the result. Finally, we rotate the slit 90° from the last position, and fit there also the strongest plus or weakest minus giving the best results.

The lens required will call for calculation and possibly transposition (Chapter XLVI), for the slit indicates the meridians where the *powers* are needed. The resultant lens is put up and modified slightly, if occasion demands, in the interest of greater comfort or better vision. In no form of hyperopic astigmatism (nor in mixed astigmatism) should the stenopaic be used *without* plus sphericals. In mixed astigmatism one principal meridian is H., and the other M., but there are two other (resultant) meridians not necessarily at right angles, in every such eye and the accidental coincidence in position of the slit with either of these may be very misleading, as such would naturally be a meridian of best sight, and yet not a principal meridian, nor emmetropic. One can readily conceive that the erroneous selection of such a meridian may at times lead to the discovery of a need for cylindrical lenses, for apparent degrees of astigmatism, which do not correspond with the amount of defect.

With aged clients the slit must be wider than with younger ones, so as to afford the best illumination of retinal image possible without defeating the purpose of the test.

Stenopaic testing depends largely for success upon the intelligence of the client. With nervous and ignorant people, and with children, it is tedious and troublesome. In medium and high degrees of astigmatism it often gives good results, and with such under the influence of a mydriatic, *is ideal*, but with the lower degrees of astigmatism it is not so accurate, giving a sharpness to the retinal image which is largely independent of the refraction, and analogous to that afforded by the pinhole, to which, within certain limits, it acts similarly.

For relaxing accommodation there can be used :—

(1). Absolute darkness, which is only applicable to objective methods of testing.

(2). Cycloplegics, if applied to the eyes by medical men.

(3). Convex lenses, which render vision indistinct and induce relaxation of accommodation *in the effort for clear vision.*

The Fogging System of Testing employs the last method. Primarily, it consists in blurring vision by plus sph. lenses, until none of Snellen's letters are visible at 6 m., and then gradually reducing the strength of the lenses placed before the eye, until satisfactory vision is obtained. This test differs from the stenopaic method, inasmuch as all meridians of the eye are accessible to the light traversing the lenses, yet it is very successfully employed in dealing with astigmatic cases, as well as errors corrigible by spherical lenses. It is specially good in cases of H. and As. in the young, because it more fully reveals latent hyperopia. When vision is blurred, the gradual reduction of the blurring coaxes the ciliary muscle to relax—in an effort to secure clear vision—where otherwise it might not do so. In myopia vision is blurred naturally, and the fogging system is not of much use, except in those *low* degrees of apparent myopia caused—or real myopia increased—by spasm of accommodation. In these cases it is often effective if blurring glasses are worn constantly for a short period.

Hyperopia, theoretically, should always be corrected by the strongest plus spherical which gives normal or the best obtainable V; so that the precaution needed in the reduction of the blurring lenses is *to reduce them as little as possible.* Wherever V is not made normal by such a course astigmatism must be looked for and corrected by the lines of an astigmatic chart. The procedure is, in hyperopic (and mixed) forms, to correct one meridian by first blurring up *all* the lines until quite indistinct, and then slowly reducing the plus power before the eye until *one* set of lines is distinctly seen. This power will be the correction in H. As. for the meridian of greatest defect (or lowest refraction), and in mixed As. it will be the correction for the hyperopic meridian. In either case it will correct the meridian at right angles to the one that *appears clearest.* The power is noted, and the selected lens is now further reduced until the bars in the opposite meridian become clear, those previously cleared becoming the most blurred. The second *power* is noted as necessary for this meridian, viz., the one at right angles to the bars now clear. A calculation is made, the lens last used being taken as the spherical, and a *plus* cylinder, equal to the difference in power between that and the other lens selected, is combined with it, with its axis in the direction of the bars most blurred with the last lens. This corrects compound H. As. If, however, the reduction of power goes on before the second bars are clear until *no lens* is before the eye, then the correction will be a simple plus cylinder, of the power first selected, and axis in the direction of the lines last seen most blurred. If, however, the second set of lines is still blurred, even when *no* lens is before the eye, we pass on, and put up minus lenses, until the *weakest* is found which clears them. This is a case of mixed astigmatism, and minus power will be required to clear one set of lines, with plus power to clear the other. Here care is required in estimating the lens needed; the simplest way is to take whichever lens has the lower power, and put that finally before the eye as the spherical, and, noting the direction of the bars now most blurred, to put on a cylinder of opposite refraction and appropriate power (that of the two known lenses added together) with its axis parallel to the blurred bars just noted. The corrective lens will be in the form af a mixed cylinder.

In myopia the sight is naturally blurred, and there is no need to fog. V. by the use of plus spherical lenses, as in H ; but we can still make use of the principles involved for the estimation of the defect, and in doing so are but carrying the method to its logical conclusion, by showing, that as it is correct in principle, it is equally applicable to all errors of refraction. In M. As. we try the power of the naked eye at 6 metres, and if one set of lines is seen clearly, the case is one of simple astigmatism (always presuming that the routine of the *plus* lenses has been already tried), and the correction will be the weakest minus cylinder, with its axis parallel to the most blurred bars, which gives clearness to all the fan. If, however, we find that *no* bars are clearly seen, then we know that *both* meridians are myopic, and we proceed to find that weakest minus spherical lens which clears one set of bars, and also the weakest minus cylinder, with its axis parallel to the bars still blurred, which, when added to the selected spherical, makes all the lines equally clear. In H, it will be seen we correct *first* the meridian of greatest defect, but in M, we correct first the meridian of least. This is done so as to correct the refraction with accommodation kept in abeyance as fully as possible, which is the great desideratum in this method.

The principles of the Fogging System as here laid down are now very extensively used in practice in all cases of astigmatism, and may be employed with many of the complete charts devised for the purpose. These usually have two devices by which the meridians of highest and lowest refraction are determined, the one consisting of the well known "fan," "sunrise" (Fig. 90), or "star," and the other of a revolving dial having two series of lines upon it, at right angles to each other.

Presuming that a case is taken where V is sufficiently good to distinguish some of the lines of the fan, it is evident, from the nature of the defect, that certain of these will be blacker and clearer than others, and generally at right angles to this position there will be a number which are greyish and blurred. Having ascertained this, either without or, if necessary, with lenses before the eye, the revolving dial is so placed that one set of lines corresponds to the best position, when the other will naturally correspond to the worst.

The problem is to get both sets of lines equally clear and distinct, and so, unless myopia has been proved, a plus lens is placed before the eye such that all lines are blurred, as + 6 D for example. Without removing this, its power is gradually lessened by holding up minus lenses in succession, carefully increasing their strength. With – 3 D in front we may find certain lines have become perfectly distinct, and therefore + 3 D (+ 6 D – 3 D) corrects the meridian of the eye at right angles to the black lines. Still continuing with minus lenses we arrive at another combination, when the lines previously the worse now become quite distinct, and, supposing that – 5 D is used, we have a resultant power of + 1 D for the meridian at right angles to the first. Taking the lower power as the spherical, the lens which should make both sets equally black is + 1 D.sph. ◯ + 2 D.cyl.

In cases of mixed astigmatism the second set of lines will need a minus lens stronger than the plus in order to clear them, and possibly – 8 D may be necessary so that – 2 D.sph. ◯ + 5 D.cyl. (or its transposition) would be necessary.

There is thus a distinct resemblance between stenopaic testing and the method above given, because each tests the refraction of the highest and lowest meridians of the astigmatic eye. We may look at the matter in another way. From the word itself (a—stigma) we see that astigmatism means "not-point" vision, and consequently we can only speak of the punctum remotum or far point as the "remotum," and there will be two of these remota for each eye, because there are two principal meridians. The distance between these remota, just as in the case of a sphero-cylindrical lens, where we have a difference in foci of two main meridians, is a measure of the cylindricity or astigmatism, for the particular position occupied by the nearer remotum. What we have to do in both the stenopaic and fogging systems is to bring both remota together upon the chart, and the difference between the two spherical lenses necessary is a measure of the cylinder required. In all cases the *meridian of lowest refraction* is corrected first, the greater the hyperopia in a meridian the lower being the refraction, and the greater the myopia the higher the refraction.

There are other variations of the fogging system of testing in addition to the two described, but the underlying principles are the same for all.

Summary :—

(*a*) Stenopaic testing excludes all meridians of the eye except the one under examination.

(*b*) Corrections found should be verified by lenses.

(*c*) The stenopaic is not very effective in low degrees of As.

(*d*) The fogging system blurs the sight artificially in order to cause accommodation to relax.

(*e*) It is excellent in young people with H. and As.

(*f*) The meanings of meridians of "highest" and "lowest" refraction, and of "highest" and "lowest" defect, should be carefully noted.

CHAPTER XXXIII.

LOW REFRACTIVE ERRORS: THEIR OBSCURITY AND DETERMINATION.

ERRORS of refraction of all kinds may exist in very small amounts in one or both eyes. They may be low in degree, and dissimilar in character in the two eyes, in which case they are likely to be exceedingly troublesome, or they may be similar in character in the two eyes, but differ in degree, when we have also a tiresome form of anisometropia. Low degrees of defect are very provocative of asthenopia and many other ocular and even bodily troubles. In the more pronounced defects there is not so much weakness and discomfort in vision, nor so much ocular headache as there is in smaller amounts of similar defects. This seems to be more particularly the case in hyperopia and astigmatism of all kinds, low myopia being an exception. There are, however, few cases of low myopia, of genuine character, which come under the optician's notice, because myopes of this class (where the defect does not exceed one dioptre), are very well satisfied with their sight, and they do not, *as a rule*, seek the aid of an optician. For near work they have vision clear and good, and, as a rule, easy. For distance, it is true, their sight is not up to our ideal standard, but generally they are satisfied with it, and in many cases, from want of accurate observation and comparison, probably do not know that it is below the average, unless they have accidently been undeceived. With real myopes of low degree, therefore, we have but little concern. When they *do* come to the optician it is merely for glasses for occasional distant use, and they are easily dealt with, care being exercised that no over correction is supplied, precisely as in all other myopic conditions.

With hyperopes of low degree, however, the case is very different. They have good vision at the expense of accommodation, and such vision may, or may not, be comfortable. If the former is the case they do not visit the optician in quest of optical aid until the advent of presbyopia compels them to do so. It is therefore with the other class that we are chiefly concerned, viz., those who obtain good vision by accommodating, at the expense of comfortable use of the eyes. These *do* come to the optician, and we will consider briefly the conditions which, in typical cases, usually present themselves. (1) Vision is normal, or close upon it. (2) Close work is described as troublesome. (3) The p.p. is at, or near the normal place for the age. (4) Plus spherical lenses are rejected at 6 m. (5) Asthenopia, photophobia, lachrymation, etc., may all be complained of. In such cases the trouble is doubtless due to concealed hyperopia, in other words to *latent defect*. At times lenses will be accepted binocularly, when monocularly they are refused ; hence the binocular test should always be applied. If, however, as sometimes happens, weak lenses are accepted monocularly, and rejected binocularly, we should suspect a condition of exophoria as the probable cause of their rejection (Chap. XXXVII.), because exophoria calls forth accommodation, which in turn conceals hyperopia, and if a pair of weak prisms, bases in, is placed before the eyes, it will be found that there is generally no difficulty in measuring the amount of hyperopia. In younger people, with little or no hyperopia manifest, but who have the p.p. further away than the normal distance, there is likely to be present fully the amount of H. indicated by the p.p., consequently the less manifest, *the more* there must be latent, and in these cases the total defect must be properly estimated. Atropine is required to fully estimate the defect, although in a darkened room retinoscopy will reveal considerably more hyperopia than subjective methods, and the direct ophthalmoscopic examination more still. Indeed, some authorities maintain that accommodation is *fully* relaxed in most cases during such an examination, but this is open to doubt, as the results obtained under atropine show.

The fogging method is good for these troublesome cases of *latent* H., and if, during testing, accommodation does not relax, the plan is sometimes followed of supplying temporary plus lenses for constant wear, "to rest the eyes." These should blur distant V. up to $\frac{6}{IX}$ or $\frac{6}{XII}$, and must be worn constantly for a week or more. If then vision has become $\frac{6}{VI}$ or better, the sight is again blurred up as before, for a similar period, by *stronger* temporary plus spherical lenses, which are again to be worn constantly. The process of "blurring up" in this way is repeated *so long as the accommodation shows willingness to relax.* By these means it is frequently possible to "coax out" latent hyperopia and make it manifest.

There yet remains a class of hyperopic cases, where, by involuntary exercise of accommodation over and above the amount required to correct refraction at 6 m., the eyes become spuriously myopic. Such a condition is said to be due to *spasm*, or *cramp* of accommodation, caused by excessive and quite involuntary contraction of the ciliary muscle. There are many likely *causes* for this condition, amongst others exophoria, over use of the eyes, excessive and close work in bad light, or working too near powerful electric lights. Being purely a pathological condition it is evident that spasm may exist with any error of refraction, and it is found in myopia and astigmatism, as well as in hyperopia. Similarly it may occur even in emmetropia. In hyperopia it produces false myopia, in myopia it increases the amount of the defect, and in emmetropia it *creates* pseudo myopia. Spasm of accommodation is therefore very misleading and the optician should be on his guard against it, but with care it can usually be recognised and dealt with.

In cases of spasm there is *always discomfort* in the use of the eyes, and near vision is particularly troublesome, which should at once arouse suspicion. In genuine low myopia near vision is good and comfortable, the eyes being naturally well adapted for close work, but in spasm distant vision fluctuates, and is better and worse from moment to moment, lenses being perhaps accepted one instant, and refused the next. Frequently even the weakest plus lenses are rejected for distance, and usually minus lenses do not give definite improvement. The p.p. in H is always beyond the normal, and minus lenses erroneously selected would remove it still further. In cases of spasm results obtained by retinoscopy vary, and do not agree with subjective tests. In myopia with spasm the myopia appears subjectively to be more than it really is, and the p.p. before correction does not therefore agree with the amount of error apparent subjectively, nor after correction is the p.p. at the normal place for the age, as it should be if the subjective determination is correct.

The best method of treating spasm is to have the eyes thoroughly atropinised, *so as to rest the ciliary* and arrive at the proper refractive condition. It is unusual to find spasm of accommodation in persons over twenty years of age, and it is very seldom met with after thirty; it is, nevertheless, occasionally present, and even in older persons, although usually as a reflex from some other condition. One very important fact helps to distinguish cases of hyperopia with spasm from pure myopia. In the former condition *plus lenses improve near vision, whereas in true myopia they do not.* Exophoria, as a cause of spasm, may be detected by the prisms previously mentioned, so that, if without them, minus lenses are apparently needed, and with the prisms on, plus lenses are accepted, spasm from exophoria is *proved.* The chief indications of spasm are first, the history of the case, and secondly, the inconsistencies shown in the positions of the p.ps. before and after correction.

Astigmatism of low degree is often very troublesome to deal with, and is apt to be overlooked. This defect should always be searched for in young people whose vision is not brought fully up to normal by spherical lenses. The fogging system, described in Chap. XXXII, is the best method of dealing with these cases, but it is important that testing be done carefully and slowly, the lenses being changed by steps of very small intervals. Low degrees of this defect are very troublesome, causing headaches, etc., which spherical lenses alone do not relieve, and when the astigmatism is against the rule, or oblique, it is often still more troublesome. As astigmatism is estimated by the *difference* in refraction in the two principal meridians, it can be corrected *either* by adding power to the meridian of least refraction, or taking it away from that of greatest refraction.

For low degrees of concealed hyperopic astigmatism, with active accommodation, we may repress the latter as fully as possible by applying plus sphericals, and then, whilst the eye is slightly myopic, because of the lens employed, correcting the astigmatism by a minus cylinder properly selected, afterwards reducing the plus spherical until blurring just ceases to be noticeable, and transposing the resulting lens. Some cases are easier fitted the reverse way, by first correcting the astigmatism with a suitable minus cylinder, and then adding on the plus sph. power as fully as possible. This is the more ideal way in low degrees of mixed astigmatism. It should, however, be remembered, that the utmost plus spherical power acceptable should always be added on, both monocularly and binocularly.

Weak lenses are often ot astonishing benefit, and low degrees of defect must not be looked upon with contempt, nor treated with neglect. Weak lenses are of most benefit to persons who, with a small amount of refractive error, have large pupils, for such people are troubled with indistinct retina images from uncorrected spherical aberration, in addition to their defect, and are particularly prone to suffer from severe asthenopia. Prentice, in his article on *iritic asthenopia*, deals with the conditions causing this, and shows clearly the value of weak lenses as a means of relief.

Summary :—

(*a*) Persons with *no apparent* hyperopia, if carefully tested, are often found to need glasses.

(*b*) Myopes of low degree, as a rule, do not visit the optician.

(*c*) Low myopia, with asthenopia in near **V.**, points to spasm.

(*d*) Spasm may occur in emmetropia, and likewise with any error of refraction.

(*e*) Low degrees of astigmatism require much care in testing.

(*f*) The fogging system is the best method of dealing with them

(*g*) Weak lenses are often of very great benefit in asthenopia.

CHAPTER XXXIV.

NEAR POINT MEASUREMENT: ITS USE AND ABUSE.

THE near point, or punctum proximum of the eye, is the nearest point of distinct vision. It is the closest point at which unaided accommodation can be used, so that, taken in consideration with the position of the far point, it becomes a measure of the range of accommodation. It is chiefly for this purpose that its determination is of interest, for, knowing the range, we also know the amplitude (Chapter XI). We shall briefly discuss here its position in Em., H., M., and Pb., and describe how it is made use of in drawing certain inferences, and how, in obscure cases, it assists the determination of defects.

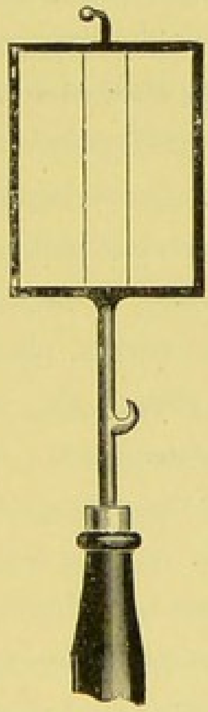


Fig. 93.
HAIR OPTOMETER.
This is a black metal frame, across which are stretched two hairs, with a small bright gold knob above. On the handle a small hook provides an attachment for the measuring tape.

At different ages Donders found, by a series of observations, that the amplitude of accommodation relative thereto was constant within certain limits, and that persons of the same age had, on an average, the same amount of accommodative power, other things being equal, and from these observations *tables* were compiled by him showing the *average* amplitude of accommodation possessed. These tables are of the utmost use to the optician, and, as the value of near point measurement depends upon them, a modified form is given below :—

Age.	Amp.	P.P.	Age.	Amp.	P.P.
10	14·00	7·0 cm.	35	5·50	18·0 cm.
12½	13·00	7·5 cm.	40	4·50	22·0 cm.
15	12·00	8·5 cm.	45	3·50	28·5 cm.
17½	11·00	9·0 cm.	50	2·50	40·0 cm.
20	10·00	10·0 cm.	55	1·50	66 cm.
22½	9·50	10·5 cm.	60	1·00	100 cm.
25	8·50	12·0 cm.	65	0·50	200 cm.
27½	8·00	12·5 cm.	70	0·25	400 cm.
30	7·00	14·0 cm.	75	nil.	∞

This table represents the average amplitude of accommodation at the age specified, and gives the corresponding position of the p.p. in centimetres for emmetropia, or ametropia after correction of the refractive error. Now, we know that in **H**. uncorrected, part of the amplitude of accommodation is constantly kept in use for the correction of the defect, and consequently that in reserve for use at the near point is less by this amount; hence, in **H**. the p.p. may be expected to be further away from the eye than is indicated in the table as the normal place for the age. In *low degrees of* **H**., however, this is not always the case, because hyperopes, through constant exercise of accommodation, frequently have an amplitude of accommodation in *excess* of the average for the age, and with such persons the p.p. may be found at, or even actually within the normal place, notwithstanding that the person is undoubtedly hyperopic; so that the p.p. at or slightly within the normal distance for the age, does *not disprove* the existence of **H**. On the other hand, if it be found further away than what is normal, then there is a strong presumption, *almost amounting to a certainty*, that hyperopia is present.

The scale of averages compiled by Donders is very reliable, and one striking proof of its correctness is the fact that the age of a person deduced from the position of the p.p. is usually found to be very near the actual number of years. In **M**., as the defect places the p.r. at a point *within* infinity, the p.p. is, correspondingly with the amount of defect, so much nearer to the eye than the normal. Unfortunately this does not *always* hold good, because, for opposite reasons to those in H., the accommodative faculty in M. is liable to be weaker than the average, as myopes usually accommodate less than emmetropes, and much less than hyperopes, so that their amplitude of accommodation is often weaker, from lack of exercise. In M., the p.p. may not, for that reason, be so near as it should be, but on account of the very good sight that myopes have at near distances, and the ability to read too close to the eyes, this weakness is not so noticeable before correction as after. In myopia the p.p. is within the normal place for the age, and if there is M., it *must be within* to an extent approaching the distance corresponding to the amount of the defect. After correction of myopia the p.p., in theory, should not be beyond the normal place for the age, but in high degrees it is beyond, as accommodative power, being wasted through long disuse, is lacking.

Summarizing, we may say that the near point, if found beyond the normal place for the age, indicates H., and when found nearer than the normal place indicates M. When the glasses which correct the refraction are before the eyes the p.p. should be *at* the normal place for the age. If in H. it is still beyond, then the difference between the place found and the normal place will correspond, in dioptres, to the amount of H. still latent. In M., if the p.p. is beyond the normal when wearing the distance glasses, it creates a suspicion of an *over* correction having been fitted, and a false condition of hyperopia created.

It is evident that the careful measurement of the p.p. indicates approximately the amount of H. or M., and afterwards helps to confirm the accuracy of the test. Spasm of accommodation is proved if the p.p. is beyond the normal position *along with an apparent myopia at 6 m.* In presbyopia also, the binocular p.p. is of great service, and if through age it is so far away as not to allow convenient measurement, it may be estimated by the aid of added plus sph. lenses, which must of course be allowed for in calculation. In anisometropia the two p.ps. will not be at similar distances from each eye, and the object, in correcting such cases, is to place the far points of the two eyes *at infinity*, and therefore the p.ps. after correction of each eye separately, ought in theory both to be at the normal place for the age. In high degrees of anisometropia this may not be so, but in low degrees, which are often very troublesome, it is essential for comfort that the two p.ps. be brought to similar distances, so that the accommodative efforts in the two eyes shall be equal. Therefore, if they are found, after correction, to be at two *different* distances, they must be made equal, either by adding to the refraction of the one lens, or decreasing the refraction of the other, or both.

In astigmatism the p.p. is no guide to the error, or its amount, and it is useless to determine it with type in the ordinary way, although it may be done for each principal meridian separately by a series of *fine* radiating (triple) lines, a tedious and somewhat uncertain procedure. In old people, as we have seen, the p.p. has to be brought up to a measureable distance by means of an added plus spherical lens, and similarly in the case of young people, where the p.p. is situated inconveniently close to the eye, it may be put back, and measured by the addition of a suitable *minus* spherical lens, the power of which must afterwards be allowed for in making the estimation. Difficulties in measuring the near point are often considerable, especially in persons with reduced acuity, who require much larger type for the determination, and then the measurement is not of much value.

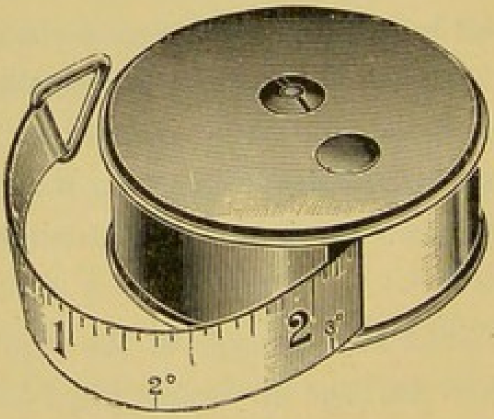


Fig. 94.

Centimetre tape measure, marked also in tangents of degrees.

The proper way to measure the near point is to find the nearest distance to the eye at which No. 1 Jaeger's small type can be read; but this is frequently not legible at all in many defects, particularly with clients who have not previously worn glasses, so that a type somewhat larger is more convenient for average use, but is of course less accurate than a finer type. Another difficulty is, that if the p.p. closely approaches the eye (as it does in young people), the intervals for successive periods in age are very short, amounting to not more than 1 cm. in many instances, so that a slight inaccuracy, or perversity on the part of a client, renders the test of little value, and it is notably in the case of young people that its indications should be most reliable. This difficulty can be lessened by the use of a concave lens as stated. Another cause of uncertainty is the varying nature of clients' statements from moment to moment, necessitating a constant watchfulness on the part of the operator. Some, trying to make themselves appear worse than they are, refuse to answer satisfactorily in any way.

The best method of taking the measurement is to commence by placing the type close to the eye, and as it is *slowly moved away*, to ask the client to say where it is *first* legible, the distance in cm. being indicated upon a suitable rule or tape. To convert the distance in cm. into dioptres of amplitude of accommodation, all that is necessary is to divide the number into 100, the result being in dioptres. Valuable as the general information afforded by the measurement of the p.p. is, yet it is not so precise and accurate as to be *absolutely reliable* in all its indications. It is beset with so many difficulties and limitations from age, visual acuity, optical errors, and mental attributes of the client, as to make its consideration somewhat complicated. On the whole, however, if used with intelligence the near point measure is one of the most useful appliances

Fig. 95.
A convenient apparatus for taking near point measurement.

that an optician possesses. It is of no use in amblyopia, squint, aphakia, high myopia, very high degrees of hyperopia, astigmatism, or extreme old age. On the other hand it is of great service as an aid to a correct diagnosis in latent H., spasm of accommodation, cycloplegia, and paralysis of accommodation.

Summary:—

(*a*) P.P. in Em. is at the average distance according to the age.

(*b*) In M., it is *always nearer than normal*.

(*c*) In H., it is *usually* further away than in Em.

(*d*) Taken with distance glasses on it proves the accuracy of other tests.

(*e*) In old age or childhood, added sphericals help its determination.

(*f*) In presbyopia, with *refraction corrected*, the p.p. should be at the normal distance for the age.

(*g*) The test is of no use in certain *specified* cases, but in others it is invaluable as a guide to a correct determination of the nature of the defect.

CHAPTER XXXV.

PRACTICAL RETINOSCOPY AND OPHTHALMOSCOPY.

IN this chapter we shall consider briefly the practical methods of retinoscopy and ophthalmoscopy, each of which, if treated fully, would need a volume in itself. A few hints will be given and a few difficulties and dangers pointed out, but for deeper knowledge reference should be made to the standard works of Jackson, The Keystone, Thorington and others.

Retinoscopy is a means of determining the refraction by observing the movement of an illumination upon the retina, caused by light reflected into the eye of the client from the optician's mirror, when the latter is rotated. Waves of light emerging from the retina of an emmetropic eye issue from the cornea parallel, but from the retina of a hyperopic eye they emerge divergent, whilst from a myopic eye they are convergent. It is found that in myopia of 1·00 D, when the observer reflects light from his mirror into the client's eye at 1 metre distance and rotates his mirror, that there is visible in the pupil a brilliant illumination, which remains quite stationary and unaltered over the whole pupillary space. The pupil then presents the appearance of a round illuminated body, not unlike a full moon, but of ruddier hue. All other conditions of refraction, at the same distance (1 m.), with the same rotation, show a movement of this illuminated area, the light vanishing from the area of the pupil and darkness following. This darkness following the light is called the *shadow*, and the direction in which it appears to travel across the pupil varies with the direction of rotation of the mirror, the curvature of the mirror, and with the nature of the refraction.

In myopia of precisely 1·00 D. there is no movement discernible. Either a plane or concave mirror may be used, or both consecutively if necessary. The plane mirror of small size, with a small perforation, and mounted as shown in Fig. 84, is recommended for all ordinary work and for beginners. The darker the room the better, because of the greater contrast presented by the illuminated area visible through the client's pupil. The light employed may be from an argand or incandescent gas burner, or an incandescent electric lamp, and a chimney fitted with a circular aperture of adjustable size (Fig. 80) should cover the light, the best aperture for general work being from 10 to 20 mm. diameter. The general opinion seems to favour the use of the plane mirror, but much depends upon the method of examination adopted, so far as the brightness of the reflex is concerned. Actually at the position of no motion both will be alike, but in emmetropia (without making the eye myopic by the addition of a + 1D lens) then the plane mirror will be better, but for medium or high myopia the concave mirror is likely to be more satisfactory, so that if the fogging system is employed in retinoscopy it is best to commence with the concave mirror. The observer must be seated 1 metre from the client, and the light placed a few inches in front and to the *left* of the operator, the mirror being manipulated before the right eye in all cases. As the intensity of light decreases inversely as the square of the distance, in order to secure adequate illumination it is imperative that the source of light shall be as near as convenient to the mirror. The client must be told to look steadily into distance, and not at the mirror; when his right eye is being tested he should look diagonally over the optician's right shoulder, and vice versa for the left eye—that is, he always looks obliquely *inwards*. The object of this is to enable the observer to direct the light into the eye along the optic axis, for in this way the refraction of the eye is obtained at or near the optic disc, the macula being too sensitive to endure the direct incidence of light from the mirror without causing discomfort. It is important that the observer himself shall be quick of perception, and his vision must not be more than slightly sub-normal when corrected. The corrective lens may be cemented to the back of the mirror.

The client must keep both eyes open. In young people the eye not under test may be fitted with a *plus* spherical lens strong enough to fog vision at 6 m., to prevent accommodation so far as possible, the object being to find the condition of the refraction of the eye when accommodation is as fully in abeyance as possible. Children with squint may have the squinting eye uncovered whilst the other is being tested, but when testing the squinting eye the good eye must be covered by a shade, so as to allow the deviating eye to fix. The client should be within easy reach of the trial case, and should wear a trial frame; the lighter single one will serve, but as lenses have to be inserted in semi-darkness the three-cell frame is preferable. We have seen that with 1·00 D. of myopia, and the observer's eye at one metre from the client's eye, no movement of the shadow is apparent. In all other conditions of refraction a movement is noticeable when the mirror is rotated, and the refraction is estimated by finding that lens, or lenses, which will produce in all meridians of the eye 1·00 D. of myopia, and so arrest all movement. As no movement indicates 1·00 D. of myopia, obviously a like amount will have to be allowed for in calculating the lens required, and this we do, no matter what the refraction, by adding—1·00 D. spherical to the correcting lens, as a compensating correction for the myopia *created* for the purpose of making the test. A good plan is to place in the trial frame before the eye a plus 1·00 D. spherical lens, thus creating the myopia at the outset, in which case the actual lens found will be the correction theoretically required, and no further allowance for "distance" is needed.

We will assume that the plane mirror is employed. In emmetropia the movement of the shadow at 1 metre is *with* the movement of the mirror, but if we render the eye myopic 1·00 D., by putting before it a plus 1·00 D. spherical lens, waves of light emerging from it will be made convergent, meeting and crossing precisely at 1 metre in front of the client's eye, and as the observer's eye is located there, it follows that the light will fall upon his retina. Now, as there is no power in the eye to adapt it for focussing convergent waves of light, the observer sees a brightly diffused image of the light projected outwards, and occupying, apparently, the area of the observed pupil. The client's retina is similarly occupied by an area of light, due to the illumination from the mirror forming upon it an image of the source of light.

The light area is at its maximum of brightness and its minimum of motion when the nodal point of the observer's eye is precisely where the emergent rays from the client's eye converge. Such a point is technically known as the *point of reversal*. It is literally the crossing point of the waves. Nearer to the client's eye than this distance, the light (and consequently the shadow) will appear to move *with* the mirror, but further away the reverse will be the case. When a reverse movement is obtained it shows that the focus for emergent light has been placed somewhere between client and mirror. What we require to do is now obvious. With any eye in which a movement of the shadow is noticeable, we have to find a lens which neutralizes that movement, when the observer is at a distance of 1 metre. Having done this, we have *made* the eye myopic 1·00 D., and so must *add* – 1·00 D. to the lens in the trial frame to find the correction needed.

The procedure seems very simple, but needs much practice. For young people a mydriatic is necessary in H. and As., but in myopia and My. As. it is not so imperative, although sometimes an advantage. In old people with small pupils and hazy media retinoscopy is difficult, and at times impossible. If the client has no lens before his eye when the plane mirror is used, we find that :—

in Em. the shadow will move with the mirror
in H. ,, ,, ,, ,, ,, ,,
in M. under 1·00 D. the shadow will also move with the mirror
in M. of precisely 1·00 D. there will be *no movement*
in M. of over 1·00 D. the shadow will move against the movement of the mirror.

In selecting the lens to neutralize the movement it is necessary to pass beyond the point of reversal and produce an *opposite* movement, so that if with a certain lens the shadow moves with, and with the next it moves against, the proper lens to select is midway between. This is the reversal lens. *Practically we find the strongest plus that leaves the movement still with the mirror, or the weakest minus that reverses the shadow's movement.* If, to gain reversal :—

no lens is needed, then there is present myopia = — 1·00 D.
if + 0·50 ,, ,, ,, ,, ,, = — 0·50 D.
if + 1·00 ,, ,, ,, ,, emmetropia
if + 2·00 ,, ,, ,, ,, hyperopia = + 1·00 D.

These corrections, as will be noticed, are all found by adding on to the reversal lens the — 1·00 D. In case a + 1 D. spherical is placed in the rear cell, the lens remaining in the trial frame after the removal of the + 1·00 D. from the rear cell will give the actual power indicated for the reversal lens. *The next weaker is usually given.*

In astigmatism, horizontal or vertical, the test must be made separately in both meridians. In fairly high degrees the appearance of the reflex will be a streak or band of light at the point of reversal of each principal meridian, because emergent paths of light from astigmatic eyes (rendered myopic), converge, not to a point focus, but as streaks of light at two different distances from the eye, corresponding to the point of reversal for each principal meridian. These are best seen when the observing eye is at one point of reversal and the source of light at the other. In oblique astigmatism, on rotating the mirror horizontally, the shadow always crosses the pupil obliquely. The correction must be found in the two principal meridians, one parallel to the edge of the shadow, and the other at right angles to it. The meridian of least defect is corrected first with a spherical, and the other by adding a cylinder, the finding always being confirmed by the test lenses in the ordinary way. Valuable as are the results, they must not be relied upon without subjective confirmation. To use the mirror the edge should be steadied against the observer's forehead, and the movement, made by a combined motion of the head and body, should be very slow, the light being made to *creep* across the pupil at a slow pace. In high defects the reflex is dull, and slow of movement. In low defects it is bright, and moves quickly. Near the point of reversal the shadow seems to "flit" across the pupil. The meridian refracted is always that corresponding to the direction in which the mirror is rotated, and in astigmatism the axis will be at right angles to the meridian along which the shadow moves (or parallel to the edge of the shadow), when refracting the meridian of greatest defect. Some authors advise each meridian in astigmatism to be corrected separately by a spherical lens; one method of working should be adopted, and consistently adhered to.

Aberrations, caused by the cornea and by differing refractive powers in the various parts of the crystalline lens, are the chief source of difficulty in retinoscopy, and with dilated pupils this is more noticeable than with small ones. Irregular astigmatism gives a peculiar swirling movement to the shadow, while spherical aberration, positive and negative (Chap. IX.), causes peculiar effects, and when either of these is combined with an astigmatic condition the so-called scissors' movement may be produced. In the case of spherical aberration an effort must be made to find the correct refraction at the centre of the pupil, and in the case of scissors' movement, by inclining the mirror slightly the peculiar appearance becomes like the ordinary astigmatic band of light, and is dealt with similarly.

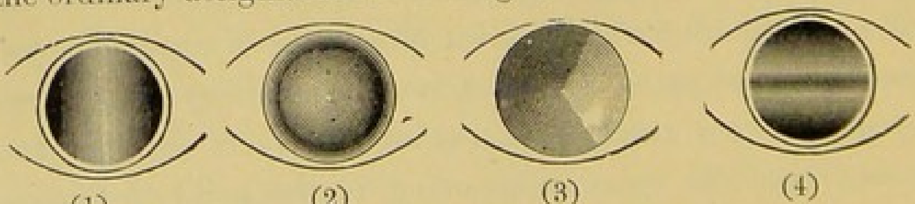


Fig 96.

(1) Astigmatism, Axis 90°. (2) Conical cornea (high negative aberration). (3) Positive aberration. (4) Scissor movement.

Astigmatism with oblique pr. mers. is difficult to correct. It should be remembered in all cases that the meridian of quickest movement is the meridian nearest to emmetropia, as it is the meridian nearest to the point of reversal. A large amount of practice is required to become a successful retinoscopist, and for beginners the model eyes made for the purpose are highly to be recommended. With a concave mirror all the movements described are *reversed*.

To inspect the condition of the living eye we use either the direct or indirect method of ophthalmoscopic examination. We will consider the indirect method first. The requirements are a concave perforated mirror of 10 inches focus and a light similiar to that used for retinoscopy, but with larger aperture, so as to get a large disc of illumination. The room must be darkened, and the light should be 3 inches or so, laterally, from the patient's head, and sufficiently far back to leave the eye in shadow. The observer sits or stands about 20 inches away from the client, into whose eye light is reflected from the mirror, held before the observer's right eye for inspecting the client's right eye, and before the left for inspecting his left eye. When the red reflex is seen the observer takes the condensing lens in his disengaged hand, and interposes it between the mirror and the client's eye, resting the tips of his third and fourth fingers upon the brow, so that light from the mirror passes through the lens both in entering and emerging from the eye.

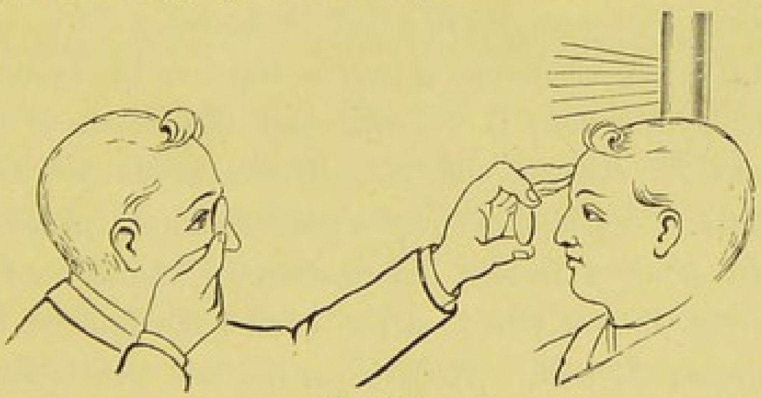


Fig. 97.
Showing positions in ophthalmoscopy by the indirect method.

This lens converges the emergent light, and a real inverted image of the fundus is formed in the air, between the mirror and the lens. If a 3 inch lens be employed, then the image in emmetropia is at three inches from the lens, whilst in H. it is further away, and in M. it is nearer. To secure a clear view of the aerial image the observer moves his own head and the lens nearer, or further away. Search is made for the optic disc, which comes into view when the client looks diagonally over the observer's contrary shoulder (turns his gaze inwards towards his own nose). In emmetropia the disc is magnified about 5 times, and when the lens is moved outwards the image remains the same size. In H. the image, which is larger than in Em., becomes smaller as the lens is withdrawn. In M. the image is smaller than in Em., but it becomes larger as the lens is withdrawn. Increase of the image of the disc in one direction more than another indicates astigmatism. To view various parts of the fundus the lens must be moved in various directions, the image viewed appearing to move with the lens, or against the observer's head, if moved. The disc by this method of examination is seen elongated most in the meridian of least refraction, providing the condenser is not too far from the eye. If surface reflections from the condenser are annoying, the lens is tilted slightly round a vertical axis, when they will usually disappear. The client can assist the inspection by slowly turning his eye upwards, downwards, inwards, or outwards, as required, and it is frequently helpful to use a plus spherical lens of 3·00 or 4·00 D. behind the mirror. To inspect the macular region the client must direct his look to a point just above the mirror, or at the observer's disengaged eye, the disc being seen on the temporal side of the condenser, when, turning the mirror towards the nose, the macula will appear on the nasal side of the lens. The client must not move his head but only his eyes. The observer, who should learn to keep both eyes open, must be seated a little higher than the client, and if an eyelid droops it may be fixed up by using the forefinger. In myopia of over 6·00 D. no condenser is needed, or if used, may be further away to *re-invert* and magnify the image, placing the eye very near the lens. A plane, or even a convex mirror may be used, if it is necessary to secure a feebler illumination. The stronger the condenser the larger the field of view, but the smaller the image: for beginners a weak condenser is best. If dark patches are seen in the line of vision they are due to opacities in the media. If the disc is seen clear and well defined at the margins, and quite sharply outlined against the rest of the fundus, as a rule good vision can be obtained by glasses. If the vessels appear to be flat and glistening there may be retinal inflammation, and blood clots, hæmorrhages, or obstructed vessels, if present, should be carefully noted, and mentioned to the oculist taking the case over. White patches about the fundus indicate a past choroiditis. A white patch near the disc may be a posterior staphyloma, due to myopia, and a cupped disc, with vessels curving over the edge, indicates glaucoma.

If the disc is unduly white, or of a slaty grey colour, there is probably optic atrophy, whilst if it appears fuzzy and congested, resembling a ball of wool, there is optic neuritis. If there are seen small red blotches and white spots upon the fundus, with a white star shaped figure at the macula, albuminuria is probable. For further information Haab's Atlas of Ophthalmoscopy should be consulted.

For the direct examination we use the small tilted concave mirror and a much feebler illumination. We first get the reflex at a distance of about 12 inches from the eye, and as the approach is made, endeavour to keep the light from the mirror upon the pupil all the time. The room must be darkened, and the client must look at a dim object 6 m. away, such as a *small* violet coloured lamp flame. The actual working distance from the client's eye in the direct examination is from 1 to 2 inches.

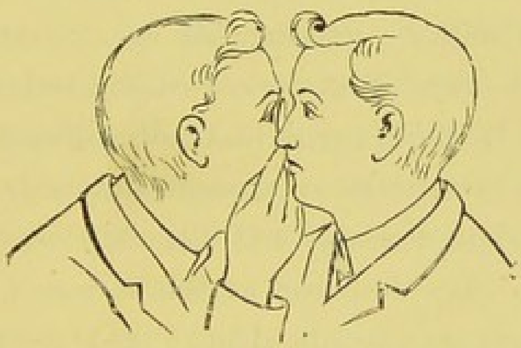


Fig. 98.
Showing positions in the direct method of ophthalmoscopy.

The tilted mirror is turned with the apex of the wedge a little above the horizontal line and pointing towards the root of the observer's nose, who should use his disengaged hand to move the light to and fro until the image of the perforation of the mirror falls on the client's pupil. The light must not be too powerful, nor too diffuse, and should be about 8 inches, laterally, from the client's ear, though some writers advocate having the lamp quite close. The use of this method, good as it is for estimating refraction, is very difficult to acquire. It is also used to look for opacities and detachments, to make a minute inspection of the fundus, and for inspecting the cornea, iris, and crystalline lens.

To inspect the cornea we place a + 30 D. behind the mirror, and to view the crystalline a + 20 D., approaching the client very closely. To examine the vitreous we use a + 10 D. and a plane mirror, at a greater distance away. Looking into an eye with a small pupil it is necessary to have a mirror with a very small perforation.

It is easier for beginners to acquire the use of the ophthalmoscope if a weak concave lens is placed behind the mirror. The right eye is examined by the observer's right, and the left eye by the left, the light being placed at the same side of the client's head as the eye to be tested. The observer should sit a little higher than the client, so that he looks slightly down, whilst the client looks up. The image viewed is an erect one, is magnified about 16 times, and moves with the movements of the observer, the optic disc being the first thing to look for. It should be of good natural colour, all the vessels normal in size and the entire disc well defined. By careful inspection minute changes in the retina and choroid may be detected, arteries, being seen on the surface, are also lighter in colour than the veins, which are visible below. To see the disc the observer directs his vision obliquely inward and backward, and should trace the course of vessels from the disc outwards to the periphery of the fundus, the client suitably turning his eye. Differences in level in different parts of the fundus are measured and estimated by the difference in refraction, 3·00 D. being equal to 1 mm. difference in level. During an ophthalmoscopic examination accommodation is generally pretty well relaxed by the darkened room and the impossibility for the client to accommodate for so close an object as the mirror. Hence refraction can, by experts, be measured to within about 1·00 D by this method, assuming that the observer has control of his own accommodation, which is a doubtful factor. Then again, the refraction at the disc differs from that at the macula, any error of refraction in the eye of the observer must be allowed for, and lastly, the distance of the lenses in the ophthalmoscope from the anterior focus of the eye requires consideration in calculating the correction.

Summary :—

(*a*) In retinoscopy, that lens is found which neutralizes the movement of the shadow in the client's pupil.

(*b*) This is done by making the eye myopic 1 dioptre, which is allowed for in calculating the required lens.

(*c*) The indirect method gives an inverted image of the fundus magnified about 5 times, and permits a rapid inspection.

(*d*) The direct method gives an upright image magnified about 16 times, and is used for refraction and minute inspection.

Chapter XXXVI.

THE OPHTHALMOMETER IN THEORY AND PRACTICE.

THE ophthalmometer is an instrument for measuring the curvature of the cornea, for taking the distance between the anterior surface of the cornea and the anterior surface of the lens, for ascertaining the position and curvature of the posterior surface of the crystalline lens, for determining the indices of refraction, and for calculating the position of the centre of rotation of the eye. Most of these uses are too academic in character to be of utility to the optician in his business. It is in the first that the instrument has its *chief value* for practical purposes, and consequently is better described as a Keratometer, measuring the convex mirror surface of the cornea by means of minute reflected images seen through a telescope. These reflections correspond to Purkinje's first image (Chap. IX.) and we have to study the relation between the curvature of the mirror and the size of the image, the shorter the radius, and consequently the greater the curvature of the mirror the smaller the image.

There are many forms of the instrument made, but an outline of two of them is really explanatory of all. The first is an older type and the second a very recent device. In the older forms, which are well known and extensively used, we find the parts as follows :—

(1) A telescope of very short focus, inside which is mounted an arrangement of prisms for *doubling* the images seen.

(2) A graduated arc of about 20 cm. radius, which when the telescope is centered and focussed on the cornea, is concentric with it.

(3) Two white objects, adjustable upon the arc, called *mires* (or *targets*), which form the corneal images.

(4) A large black disc forming a background for the mires.

(5) An adjustable chin support for clients' use, with 2 eyeshades, illuminating attachment, and reflectors.

(6) A heavy metal base, with adjustments for the telescope.

(7) An indicating disc, fitted with two pointers, and graduated for all meridians.

(8) An artificial cornea for testing the instrument.

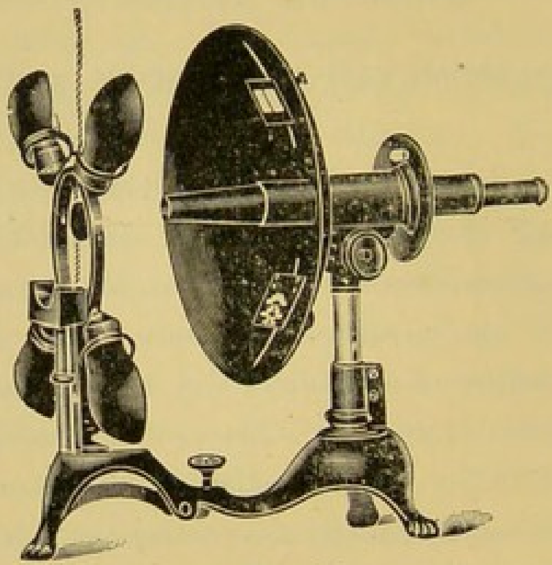


Fig 99.

In Chap. V. we saw that given the size of O and I, with distance *u*, the radius of curvature of a mirror can be found. The mires are, for average corneal curvatures, set on the arc at 22 cm. apart, and are adjustable either nearer or further as required. The arc is 28 cm. distance from the cornea. Each step of the mires is 5 mm. wide, and the instrument is so constructed that a displacement of 5 mm. in the position of the mires is equivalent to 1·00 D. of astigmatism. The prism employed for doubling the images, in doing so displaces any two corresponding points of the images 3 mm. apart, and the plane of this doubling coincides precisely with the plane of the arc. When the images seen on the cornea are the same size as the deviation produced by the prism, then, obviously, the edges of the images will *just touch each other*.

If, however, the images do *not* touch each other they are not the same size as the deviation produced by the prism, and from the amount of adjustment (of the object) required to bring the images to the proper size we can *calculate* the size of each reflected image. In the meridian of greatest curvature we get a smaller image with closer parts, but as the deviation of the prism is constant the images are (apparently) thrown further over each other, and the mires overlap more. Clearly any deviation in the size of the image must be due solely to variation in curvature of the cornea, as the other factors are constant. When the images appear to separate, it is because the image as a whole is larger, and the parts wider, and, as the deviation of the prism does not vary, the inner edges of the images do not now touch each other, but fall short and appear to be separated. The greater the difference in curvature of the two principal meridians the greater must be the apparent overlapping or separation. We have seen that according to the law of reflection the longer the radius of curvature the larger will be the image, and the shorter the radius the smaller the image ; so that when the images overlap it shows *greater* curvature, and therefore greater refractive power in that meridian ; and when they separate it shows *less* curvature, and therefore less refractive power in that meridian. If the images neither overlap nor separate, the corneal curvature is uniform, and consequently there is no corneal astigmatism. The *average* radius of curvature of the cornea is 7·829 mm. (Helmholtz), but there is no such thing as *normal* curvature of the cornea, and variations from the average are common. The curvature of the cornea, therefore, cannot be taken as *indicating* either H. or M., but nevertheless it *suggests* a lower or higher refractive power. The ophthalmometer does not diagnose either H. or M., it merely measures the corneal radius, and shows the *difference* between the two principal meridians, indicating their position. Donders found that there was absolutely *no definite relation* between the radius of curvature of the cornea and the refraction of the eye.

As the area of the cornea occupied by the images is only about 3 mm. in diameter, they should be well centered, so as to occupy the optic part of the cornea. An accurately made ophthalmometer is sufficiently sensitive to show variations of corneal curvature produced by a difference in its radii of ·01 mm. The corneal image of each step of the mire does not exceed ·1 mm. in diameter. The prism doubles these images, and the distance between any two corresponding parts of the doubled images is exactly 3 mm. ; therefore, when the two inner edges of the mires are set apart upon the arc so as to cause the two inner edges of the central images just to touch, the image is precisely 3 mm. long. The graduations on the inner edges of the right and left arcs, which are each ·5 cm., correspond to the size of the steps on the mire, and when *added* together (read at the inner edge of each mire) will give the approximate refraction of the cornea in dioptres, the graduations on the outer edges of the arc indicating mm. of corneal radius.

In using the instrument the illumination must be good, the client's eyes wide open, and the face quite level, with the head steadily resting against the supports, the eyes looking straight ahead. The telescope must be focussed on the eye and centered properly, with the mires in the horizontal meridian, and the two pointers at 90° and 180°, the other eye being occluded.

Two black "guide" lines run through the mires, dividing them into two halves, and when these are in precise alignment one of the principal meridians is located.

The two principal meridians are found roughly by noting the position of the pointers when the guide lines appear in approximate alignment, and when the pointers are at 90° and 180° it is not necessary to rotate the telescope more than 45° either way to locate the principal meridians. One thus indicated in which the images are *furthest apart* is that of *least* refraction, and the images are now approximated and the "guide lines" placed in coincidence and correct alignment, the exact situation of the images thus found being called the "first position." Without attempting to touch the focussing screw of the telescope, and without taking the eye away, the tip of the thumb of the *left hand* is placed against the tip of the pointer to the meridian of the "first position," and the telescope rotated until the tip of the second pointer, which indicates the "second position," is felt to come similarly against the thumb, with the guide lines again in strict coincidence. The amount of overlapping of the images is read off. The astigmatism is recorded by the difference of overlapping in the two principal meridians, but if there is no overlapping then there is no corneal astigmatism. If in the second position the alignment is imperfect there is *irregular* astigmatism.

Plus cylinders, at or about 90°, or minus cylinders, at or about 180°, denote astigmatism "with the rule." Plus cylinders, at or about 180°, or minus cylinders, at or about 90°, are denominated "against the rule." Axes of 45° and 135° being exactly intermediate are *neither* "with" nor "against" the rule.

The main differences in the type of ophthalmometer described are in the shape of the mires and variations in movement of either prisms or mires. An excellent form is the Chambers Inskeep with mires of horse shoe shape.

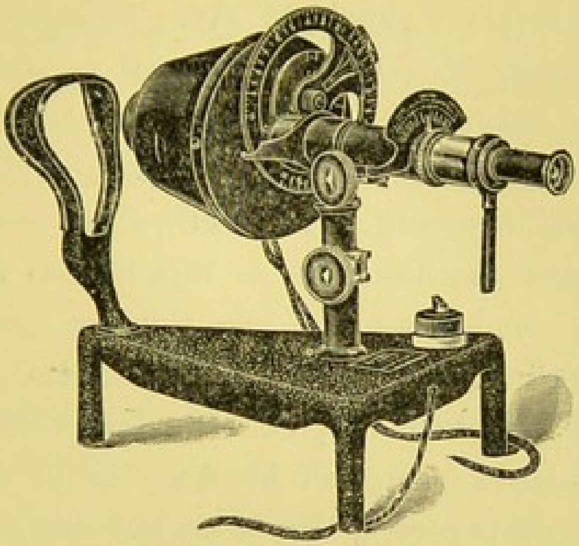


Fig. 100.
The Sutcliffe Keratometer.

Above is illustrated a "one position" Keratometer, a single mire, centrally placed, being employed, and this, by a French device of triple crossed decentered cylinders of weak power is made to produce three images, two of which are doubled by any inaccuracy of focus. Alignment and contact are obtained in first and second positions as described above, but the manipulation is simpler.

In addition to corneal astigmatism, an inverse or opposite astigmatism of the crystalline lens exists in most eyes, and of such character that it tends to neutralize the corneal when with the rule, and to increase it when against the rule. An allowance has to be made for this by *adding* from 0·25 to 0·75 D. when the astigmatism is against the rule ; and *deducting* a like amount when it is with the rule, 0·50 D. being the average amount. Thus astigmatism of 0·50 D, with the rule, *might* require no cylinder ; whilst 0·50 D. against the rule, *might* require 1·00 D. cylinder. Similarly, no corneal astigmatism might need 0·50 D. against the rule, (either + at 180° or − at 90°), and 0·25 D. with the rule, might need 0·25 D. against the rule, for accurate correction, caused in every case by the astigmatism of the crystalline lens, which is possibly due in most eyes to a slight tilting of the lens. The ophthalmometer merely indicates *so much astigmatism*, which may be corrected by a plus cylinder at ...° *or* a minus cylinder at ...°. We commence by trying plus cylinders, weak ones at the outset, and gradually increase them to the amount indicated, so long as vision is *improved*. If plus cylinders are accepted, we try to add on plus spherical power, which, if accepted, proves a condition of compound H. As. If rejected, and the plus cyls. alone make vision normal, the case is one of simple H. As. If, however, plus cyls. do *not* satisfactorily improve V., although accepted as affording *some* improvement, and plus sphericals, in addition, are rejected, we immediately suspect mixed astigmatism, and try weak minus cylinders at right angles to the plus already accepted ; if V. is further improved mixed astigmatism is determined, and the correction is adjusted, so as to secure the best vision possible. Supposing that plus cylinders are utterly refused, we then try minus cylinders alone, at the axis indicated, and if vision is not raised to normal we try minus sphericals *in addition*, the former correcting simple, and the latter compound M. As. In all cases, before ordering cylinders, two separate tests should be made. By this method cylindrical lenses are fitted before sphericals, but in some cases it does not work well, and where the spherical error is considerable it is often better to correct that first, always taking care not to over correct the meridian of least defect, i.e., not to fit sphericals too strong before cylinders are fitted. Any additional spherical power required can easily be given after the cylinders are selected.

Irregular As., from ulcerations, etc., may be associated with regular astigmatism, in which case the latter can be measured approximately by the ophthalmometer, and the correction tried experimentally if it affords improved V. In As., after cataract operations the ophthalmometer is only useful for finding the axis, and as the spherical lenses required are usually strong, they should be fitted first, and the cylinder giving the best vision fitted afterwards, *at the axis indicated.*

The ophthalmometer is very useful in squint with astigmatism in the deviating eye, the axis and amount of corneal astigmatism being easily determined, when subjectively it is quite impossible to do anything. If confirmed by the retinoscope and ophthalmoscope the cylinder indicated may safely be ordered along with the spherical, when such is needed.

The ophthalmometer measures astigmatism at the surface of the cornea, but we saw in Chap. XXII. that a lens in the usual position at the anterior focus of the eye would be weaker, if plus, and stronger, if minus, than one in contact with the cornea, and this explains why in aphakia the finding is only useful for locating the axis, a glance at Fig. 73 sufficing to indicate the variation in power of a lens in the two positions, the table in the same chapter giving the exact differences.

Unfortunately, in the most troublesome cases of low degrees of As., the ophthalmometer is not a safe guide, and where it is most reliable for axes—in medium and high degrees—there subjective testing, if well done, rarely fails.

Summary :—

(*a*) The ophthalmometer locates two principal meridians, and measures corneal curvatures.

(*b*) It does not indicate H. or M.

(*c*) Lenticular astigmatism is present in most eyes, and needs consideration.

(*d*) Distance of cylinder from cornea should be allowed for in prescribing.

(*e*) For aphakic patients the instrumental indications as a rule are too high.

Chapter XXXVII.

THE PHOROMETER AND MUSCULAR IMBALANCE.

FOR sustained action of the two eyes in perfect binocular vision it is necessary that the external muscles of both shall be capable of acting harmoniously, and that the forces controlling their united action shall be working in perfect equilibrium. The functions of the external ocular muscles (Chap. X.) are to move, direct and steady the eye-balls. The movements required are rapid, and complex in character, and to a large extent are performed automatically, without consciousness of serious effort, and in health are without visible tremor or jerkiness. As previously explained, the actual direction of the optic axes of the two eyes, during *complete repose*, is one of divergence. This, the *anatomical* position of rest, is assumed by the eyes when all outside influences likely to affect the action of the ocular muscles are excluded, but all other positions of the eyes must be maintained at the expense of muscular contraction. For binocular V. at 6 m. (or over), parallelism of the visual axes is requisite, and this is called the normal *functional* position of rest.

When the optic axes are so directed the muscles are in the neutral position of normal equilibrium for properly balanced conditions, and this should always obtain for infinity. At 6 metres (or 20 feet) positive convergence commences (Chap. XI.). Movement of the eyes *outwards* from this position is natural normal divergence, and movement inwards is convergence. Any want of muscular balance is due to a dislocation of these two functions of convergence and divergence from the normal position of neutrality or parallelism. Parallelism of the visual axes at 6 m. is termed orthophoria, and in this condition neither pair of opposing muscles is exerted more than the opposite pair to produce parallelism of the visual axes. Correctly balanced action of the muscles of both eyes is necessary to preserve the fusion of images for perfect binocular vision, and in speaking of muscular insufficiency we refer to the relation between two sets of opposing muscles rather than the actual weakness, or excess of strength, of any one muscle. If the visual axes *tend* in any other direction than parallelism when adjusted for infinity the condition is termed heterophoria, of which there are several kinds, e.g., *esophoria*, tendency of axes inwards, *exophoria*, tendency outwards, and *hyperphoria*, tendency for one visual axis to place itself higher than the other (called by some authorities *anaphoria* and *kataphoria*). We have also classifications of other compound deviations from parallelism, as *hyper-esophoria*, tendency upwards and inwards, and *hyper-exophoria*, tendency upwards and outwards. Almost all these conditions are sources of discomfort in the use of the eyes.

Some knowledge is necessary as to how muscles act, in order to gain a correct understanding of the subject. The external muscles of the eyes, with which alone we are at present concerned, are voluntary muscles, and are largely, though not entirely, under the control of the will. They can only do work by contracting, that is by shortening, or reducing the distance between their ends, and in a continuous state of contraction often develop a condition of cramp. This arises in such muscles as are overworked or irritated, and is spoken of as "spasm," which may be defined as a more or less permanent contraction of a muscle over and above the necessity of the condition, and one that does not spontaneously relax even when the necessity for its contraction is removed. Spasm in a muscle, therefore, shortens its length. Paralysis of a muscle, on the contrary, lessens its power to contract, with an effect the opposite to spasm, for it tends slightly to lengthen. It will be gathered from what has been said that we may have 'spasm of convergence,' just in the same way as we have spasm of accommodation.

"Muscular insufficiency" means a want of strength to overcome any imbalance, and not a real physical weakness or insufficiency in the actual muscular strength. A *manifest* imbalance is one that shows itself, while a *latent* imbalance is concealed or created by over action of an opposing rectus, as when apparent insufficiency of the externi is really due to spasm of the interni. Muscular insufficiencies are really latent concomitant squints, the manifest insufficiencies being the actual squints and the ocular paralyses, with which the optician has little concern. The latent errors of muscular balance are concealed in the interests of binocular V., and the effort made by nature to conceal them is no doubt the chief cause of asthenopia and discomfort.

In testing for muscular imbalance we must first be assured of the presence of binocular vision, as otherwise there can be no imbalance which can be tested subjectively. Any of the ordinary tests will suffice, such as the reading bar test, the single prism test, or the stereoscope and two lines test. The Maddox rod is an excellent test for binocular vision, but it is better to employ the simpler tests first, in order that no misapprehensions may arise in the mind of the client. If binocular V. does not exist, any subjective questions about "candles and streaks" are very confusing to those who are not familiar with what is referred to.

Errors of refraction should always be corrected before testing for muscular imbalance, which is done at 6 m, the glasses correcting the refraction being worn. The first thing is to produce diplopia, either by creating with prisms such an amount of difference between the two eyes that the muscles cannot possibly overcome it, or by the better method of entirely dissociating the two eyes in the act of vision by producing two dissimilar retinal images, and so doing away with all desire for single vision, thus allowing the eyes to assume, as nearly as they can, their functional position of rest. The best means of doing this is to place the multiple red (Maddox) rod before one eye of the client and a disc of vivid green glass before the other. The test object is a small bright flame against a suitable background at 6 metres, the room being partially darkened. On the wall immediately behind the flame, and with its centre aligned with it, is placed a "deviation chart," *drawn to scale for the distance.* Each optician should construct his own chart to suit the length of his testing room and the system of numbering his prisms. The easiest to make, and usually the most convenient, is the prism-dioptre scale (see Tables at end). The chart constructed to measure horizontal deviations should be marked from the centre towards the right in black figures, and towards the left in red ones; that for vertical deviations should be marked with the red figures above and the black ones below.

In testing the horizontal muscles (external and internal recti) it is usual to place the Maddox rod horizontally before the R. E. of the client. A *vertical streak* of light will be seen, whilst the left eye, before which the green glass is placed, *sees only the flame.*

In orthophoria the streak of light will pass through the flame, but in heterophoria it will appear displaced either to the right or left. *This* *deviation always takes place in the direction of the weak muscle.* The cornea is, however, always deviated in the opposite direction from that in which the streak is seen. If the streak appears on the same side of the flame as the rod is placed it indicates esophoria, or tendency of the visual axes inward, caused (usually) by weakness of the external recti ; seen on the other side of the flame it indicates exophoria, or tendency of the visual axes outwards, and weakness of the internal recti. To test the vertical muscles the Maddox rod is placed vertically, a horizontal streak being now seen. In orthophoria this passes through the flame, but if it is seen above or below the flame hyperphoria exists. Here again the streak is deviated towards the weak muscle, the eye which views the highest object (streak or flame) being the one that has the *lowest* visual line. Assuming that the rod remains before the R. E., any corrective prism would be placed with its base in the direction of the streak if placed before the R. E., and with its base in the contrary direction if before the left eye. With the rod before the R. E., if the streak is seen below the flame the condition is one of right hyperphoria, but if above the flame it is left hyperphoria.

The muscles are also tested in near vision for horizontal insufficiencies. This may be conveniently done by means of Maddox's small tangent scale, constructed for a distance of 25 cm., and graduated in prism dioptres, with the right hand figures in black, and the left hand in red. Metre-angles may be marked by asterisks above the graduations to suit any arbitrary pupillary distance selected, or different scales may be constructed for various p.ds, if accuracy in this respect is required. A few words of small print are usually placed under the graduations, to make sure that the person tested is able to accommodate for the distance (25 cm.) at which the test is made. Similar charts can, if required, be easily constructed for other distances.

To make the test a prism of 10 or 12 dioptres is placed, base up, before the R. E. Diplopia is immediately created, and the client holding the card at 25 cm., sees two scales with two arrows, one beneath the other. He must be instructed to regard the lower one, and is asked to what figure in the line above the arrow points, and also whether the figure is black or red. As a check on the accuracy of his statements he may also be asked what word in the printed sentence the arrow points to. The lower arrow is the one seen by the R. E., and if it wanders across to the red figures, on the left in the line above, the diplopia is crossed, and exophoria is indicated (i.e. latent divergence), the eye being deviated outward, and the false image inward towards the weak muscle, in this case the internal rectus. If the lower arrow is to the right, the diplopia produced by the prism is homonymous, indicating latent convergence, or esophoria. It is a natural and normal condition to have a small amount of *exophoria* at a distance of 25 cm., and we may therefore consider it physiological to find from 1 to 2 m. a. Variations at this distance are not nearly so important as at 6 m., unless esophoria is proved. If the visual acuity is low, and the client does not see the figures on the deviation chart at 6 m., we simply find that prism which, placed base over the weak muscle, corrects the deviation of the false image.

The best routine in testing the muscular balance is to test for horizontal deviations first, at infinity, then for vertical deviations, and afterwards for horizontal deviations in near vision. The correction of hyperphoria is the most important, next comes esophoria, and last exophoria. It is essential that the rod, prism, phorometer or other instrument be accurately set before the eyes, and that the trial frame be level and well centered. The client's head must be straight and stationary. Esophoria and exophoria usually require no correction beyond the spherical lenses which restore harmony between the efforts of accommodation and convergence. In some very marked cases, where treatment of the refraction alone does not relieve or cure the asthenopia, some prismatic aid may be given. Hyperphoria, on the other hand, generally has to be corrected by prisms, at any rate if the asthenopia is constant and troublesome. All tests should be made with the glasses on which correct the refraction, except in the case of hyperphoria, when they are not required.

In selecting prisms never more than half of the indicated defect is corrected, and several different tests are made to fix the amount satisfactorily, the corrective prisms being placed with the bases over the weak muscles. It is better to divide the prismatic power equally between the two eyes, and for horizontal deviations the prisms are either placed *both* with bases in, or both with bases out, as the case requires ; but in vertical errors one prism must be placed base up *and the other base down*. It is rare that prisms stronger than 4^{Δ} before *each eye* can be tolerated. Prisms unnecessarily given create rather than cure a muscular weakness. At best they do but afford relief by merely resting the weak muscles, which consequently may tend to get actually weaker during their use. In **H.** or **M.** with weak muscles relief can generally be given by the judicious selection of lenses according to the following rule :—With esophoria give plus lenses strong and minus lenses weak ; with exophoria give minus lenses strong and plus lenses weak (subject of course to the usual safeguards).

Simple hyperphoria rarely exceeds 4°.

Esophoria (with binocular vision) rarely exceeds 10°.

Exophoria (with binocular vision) rarely exceeds 8°.

Where diplopia is present there is no *necessity* to use the Maddox rod, though no error would be introduced by using it. We must remember that when prisms are worn the eyes still deviate, but single **V.** is maintained by means of the prisms, and thus the *effort* to maintain single **V.** is saved and greater comfort is produced.

The metre angle varies with the p.d., being largest when this is widest. Prentice's rule for its calculation is as follows. "Read the p.d. in cms., and take half of it to indicate the prism dioptres necessary to substitute one metre angle for *each* eye." From this we can easily find how much prismatic power would have to be either placed before one, or divided between both eyes, to give any required number of metre angles of convergence. If, for instance, the p.d. is 60 mm., the half of this is 3 cm. and the metre angle will be equal to 3^{Δ} (each eye).

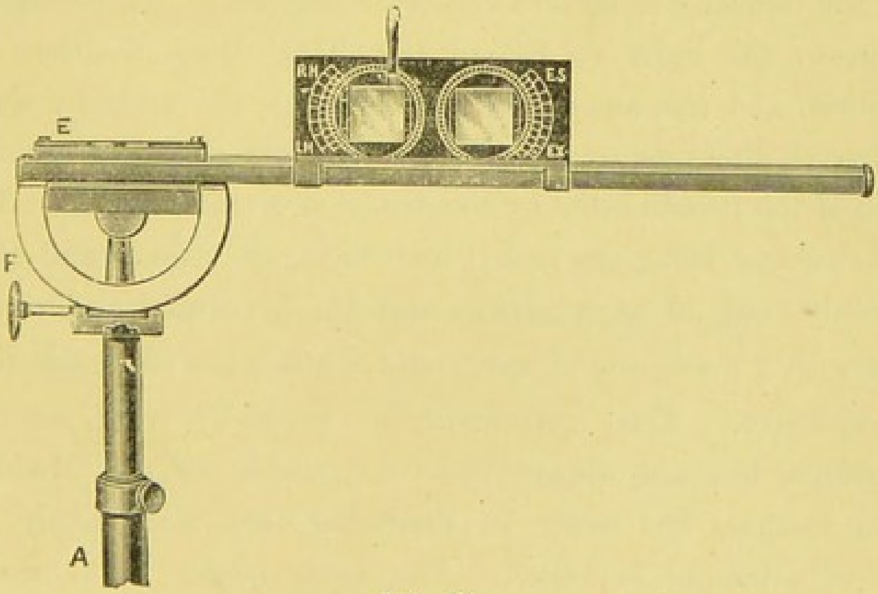


Fig. 101.
Stevens' Phorometer.
A—Pillar, adjustable for height. E—Spirit level. F—Thumb screw.

An instrument designed for the quick estimation of muscular insufficiencies is the Stevens' Phorometer, an arrangement whereby two prisms are placed before the eyes in such a way that they can be rotated in opposite directions. They are mounted in a suitable holder upon a horizontal arm, which swings upon a vertical pillar and can be locked in any position. The horizontal arm is adjustable for height, and the prisms can also be levelled by means of a finely adjusted screw and lever, a "spirit level" being attached to the instrument. The two rotary prisms are of equal power (5°), and when the pointer is set for zero on the first scale they are both bases in, thus creating a horizontal diplopia when the eyes look through them (from a distance of a few inches), at a candle flame placed 6 m. away. The instrument is graduated with a scale from 0° to 10°, the latter figure representing the combined power of the two prisms when both are at their position of united maximum effect. If, when the instrument indicates zero, the diplopia produced does not show the two candle flames in a horizontal line with each other, but one higher than the other, there is hyperphoria, and the amount of rotation of the prisms, as indicated *on the scale*, measures the *amount* of the imbalance, and the nature of the rotation tells the direction of the visual axes. Similarly, when the prisms are set in the position employed in testing the horizontal muscles, the vertical diplopia produced by the prisms (which are now adjusted one base up and the other base down), should be of such a character that the two candle flames are seen in precise vertical alignment when the indicator is at zero on the *second scale*. If, however, one candle is seen to the right or left of the other there is either esophoria or exophoria, and the amount is indicated on the scale by the amount of rotation of the prisms required to correctly align the candles, and the nature of the insufficiency by the direction of the rotation. The scales of the instrument being graduated both ways, the defects and their amounts are easily read off at a glance, and the horizontal and vertical muscles tested with a maximum of speed and a minimum of trouble to both client and operator. The instrument is generally very accurate in its indications, but not always quite so reliable as the Maddox rod, the retinal images, not being so dissimilar, are more likely at times to allow of attempts at fusion. The more recent forms are fitted with two Maddox rods of coloured glass in addition to the rotary prisms, by means of which this fault is obviated. In these later instruments there are also metal rims for carrying test-lenses, etc. The phorometer will not do anything that cannot be done equally well, or better, with the Maddox rod, but it is less troublesome in manipulation, and is a considerable time saver.

The ocular muscles should be tested in all asthenopic cases, in all cases of periodic squint, and wherever ordinary refractive corrections are not comfortable in use.

Summary :—

(*a*) The ocular muscles are in equilibrium when the two visual axes are directed in parallel lines to infinity without conscious effort. (*Orthophoria*).

(*b*) Tendency of the visual lines otherwise is called *heterophoria*.

(*c*) Latent heterophoria is muscular insufficiency (imbalance)

(*d*) Manifest heterophoria is squint or paralysis.

(*e*) For testing, the eyes are dissociated in binocular vision by means of the Maddox rod, the insufficiencies being then measured by the deviations produced.

(*f*) The corrective prisms are always placed *bases over the weak muscles.*

Chapter XXXVIII.

THE PERIMETER AND THE FIELD OF VISION.

THE field of vision has been defined as the area of the percipient part of the retina upon which the images of objects are perceived whilst the gaze is fixed upon one point, the other eye being occluded. By mapping out this area we learn whether the sensibility of the retina is defective in any essential part. For *roughly* testing the field of vision the outspread fingers of the operator's hand are sometimes used, and for ordinary investigations a blackboard placed about 18 inches from the client's face is frequently employed; but for *accurate* estimation a perimeter is required, by means of which the field of vision can be outlined upon a properly constructed diagram or chart. Defects in the field of vision occur chiefly in two varieties :—

(*a*) As concentric contractions in the percipient area of the retina.

(*b*) As blind patches or gaps, known scientifically as *scotomata*.

If the former condition is present it is either indicative of pigmentary changes due to retinal degeneration, or of a glaucomatous condition. A scotoma, however, may be found in *any* condition of the fundus in which a definite portion of the retina is so affected as to prevent it fulfilling its functions, such for example as may occur in choroiditis, retinitis, etc. The percipient area of the retina is always smaller for colours than for white (Chap. VIII.), and in certain diseases affecting the optic nerve the field of vision for colours shows contractions before that for white. In tobacco amblyopia (Chap. XVII.), and some other toxic affections of the optic nerve there is a well defined central scotoma for certain colours.

The perimeter (Fig. 102) is an instrument for taking records of the extent of the field of vision and for several other purposes which will be described later. It consists of a heavy base, with an upright pillar carrying a semi-circular arc graduated in degrees both ways from the centre outwards. This can be placed to *correspond with* any of the meridians of the eye, by rotating it around a pivot in the centre. At the opposite end of the metal base an upright post is fixed, carrying an adjustable chin rest, which can be so fixed as to bring the eye directly opposite to the centre of the graduated arc. There is also a carrier running freely along the arc from one end to

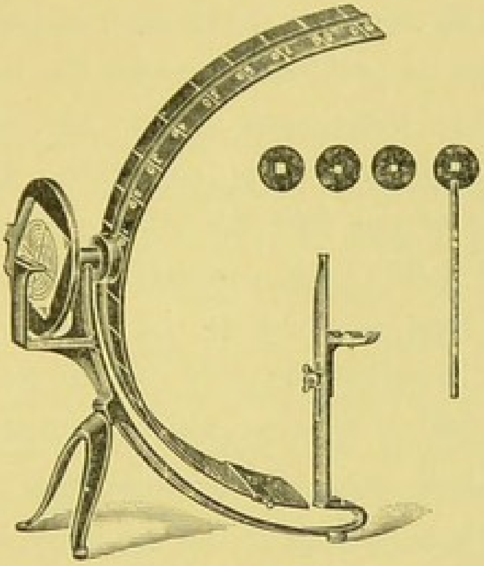


Fig. 102.
The Perimeter.

the other, for the purpose of holding the test object, which for white is a small disc of white paper, and for colours small squares or discs of coloured paper. The tests are made by moving the slide carrying the disc along the arc from the periphery towards the centre in the various chief meridians. At the back of the arc is a metal chart-holder which rotates *with the arc*, and brings each successive meridian of the diagram into alignment with the fixed gauge plate. This gauge is graduated in degrees outwards from its centre to correspond to the size of the chart employed, so that it is easy to mark off precisely the limit of the field of vision in every meridian by dotting upon the chart as the arc is revolved. The dots made are afterwards *united* by a continuous line, and thus a map of the outline of the field of vision is obtained upon the chart.

As all retinal perceptions are inverted relatively to the position of the object outside the eye, it follows that the right side of the diagram corresponds to the left side of the retina, and the upper half of it to the lower half of the retina. The charts have generally an outline placed upon them by the makers indicating the normal field of vision, so that when the observations and diagram are complete it can be seen how far the field of vision varies from the average in any particular case. The *centre* of the chart corresponds to the *macula*, the blind spot being figured to the nasal side of this. To compensate for retinal inversion *the charts are inverted when placed in the instrument*, so that, when removed, the resulting diagram corresponds to the exact retinal area investigated.

There are many visual conditions in which it is better to sweep the field in circles rather than in meridians. In cases of hemianopsia or of sector like defect such a course is preferable, because the boundary line of the field runs *meridionally* in these cases. The test object is placed (for this purpose) in the clip, and swept round the field in successive circles. During the taking of the field the other eye must be covered by a close fitting shade, the head kept perfectly stationary, and the gaze fixed intently upon the fixation point at the centre of the arc. The field of vision so obtained is called the *field of indirect vision*, and must not be confused with the field of fixation, which is totally different.

To test for scotomata, after noting the extreme limit of the field of vision (the point nearest to the extremity of the arc at which the test object is *first* seen), the slide with the disc must be slowly carried right up to the centre of the arc. If the disc should disappear or become blurred at any point, this must be marked upon the chart, and also the point where it again appears as it is carried still further towards the centre. This must be done in *every chief meridian*. Thus spots of deficient perception upon the retina are readily outlined upon the chart, but care must be taken *not* to consider the natural blind spot as a pathological scotoma. The blind spot (optic disc) lies a little to the nasal side of the macula and a little below the horizontal meridian : viz. 15° inward and 3° downward, approximately. By observations made at different times it is easy to tell whether the field of vision is contracting or becoming larger, and also detect the increase or measure the extent of any scotomata that may exist.

Generally the field is tested in only four of the twelve chief meridians, namely at 45°, 90°, 135° and 180°, but any number may be similarly examined. The usual extent of the external field is *about* 90° outward, 50° inward, 65° downward and 45° upward, the field being smaller when the object is on the inward side because the field of view is restricted by the nose. Should the outer half of the field be absent (representing the inner half of the retina) the condition is hemiopia (or half vision), the *seeing* half of the retina being the outer one.

The field of fixation, or field of direct vision, measures the range of *movement* of the eye, and can be taken by the perimeter very easily, a word of small print being moved along the arc from the centre outwards in each chief direction, until the print can no longer be read, that is until the visual axis can no longer follow its movement. The client *must not* move his head, but only his eye, the usual extent of the eye's movement each way being about 45°. These indications are of value in cases of ocular paralysis.

The perimeter may also be used to measure the angle of squint, the client being placed with the squinting eye opposite to the centre of the arc, with both eyes uncovered. The good eye fixes a distant object in line with the centre, but the visual axis of the squinting eye is *misdirected*. The observer, who sits behind the arc of the perimeter, moves a small lighted taper along the edge until he sees its image reflected from the centre of the cornea of the squinting eye. The angle of deviation is then read off upon the arc of the instrument. In cases of very strongly convergent strabismus, when the deviating eye turns in *so closely* to the nose as not to allow the reflection of the taper to be observed, a prism, base in, before the squinting eye, may be employed, to throw the light upon the centre of the cornea. Half the strength of the prism, added to the amount given by the perimeter, will show the number of degrees of deviation of the squinting eye.

The binocular field of vision may be found by superposing the two diagrams, thus obtaining the position common to both (Chap. XII). In the middle of this diagrammatic area lies the fixation point, and on each side of it are situate the blind spots of the R. and L. eyes.

In taking the fields for colours it must be remembered that the object can be *perceived* sooner than the colour can be recognised, and the point required is not where the object is first seen, but where the colour is first correctly recognised. The perception of light in the different parts of the field is ascertained by passing a candle flame along the arm of the perimeter, and if vision is very defective a second candle is made use of for a point of fixation.

The perimeter is a valuable instrument in the hands of a skilful operator for helping to diagnose retinal changes such as are brought about by choroidal and retinal affections. Contraction of the visual field is one of the very *earliest symptoms* of glaucoma, but it also occurs as a consequence of advancing years. Central colour scotomata are generally found in toxic amblyopia, and are aids to diagnosis.

Medical men requiring information about the percipient power of the retina may send patients to have the field of vision mapped, and will then generally indicate to the optician precisely what they wish to ascertain. No information should in such cases be given to the patient, but a chart, with the date, patient's name, and any needful explanation appended, should be delivered privately to the doctor.

The perimetric examination of an eye is not usually made until after other subjective and objective tests, the ophthalmoscope frequently indicating its necessity.

Summary :—

(*a*) In taking the F. O. V. the gaze of the client is kept fixed on one point, the other eye being covered.

(*b*) A blackboard may be used for taking the field, but a perimeter is better.

(*c*) The result of the investigation is recorded in diagrammatic form.

(*d*) The outward field is inverted in position upon the retina.

(*e*) The point of fixation corresponds to the macula.

(*f*) Contractions or gaps in the visual field indicate retinal defects.

Chapter XXXIX.

PRESBYOPIA AND THE FITTING OF BI-FOCAL LENSES.

THE refraction of the eye when at rest is called its *static* refraction, the word static meaning "standing" or "quite still." But when the ciliary muscle contracts the refractive power is increased, and the amount of increase is known as the "dynamic" refraction. An emmetropic eye viewing distant objects has static refraction only exercised, but turning to close work calls forth dynamic refraction also. Presbyopia is due to the gradual loss of ability to produce this.

Probably the correction of presbyopic conditions finds the optician most of his work in testing, for presbyopes, more than any other class of customers, come through compulsion. The nature of the trouble, increasing with advancing years, compels their attention, as work and pleasurable recreation at a *near distance* are impossible without some optical aid. The usual symptoms of its onset are the removal of reading matter to a greater distance from the eye, complaint as to insufficiency of artificial light, which is often brought between the book or newspaper and the eye to obtain better illumination, and the frequent blurring of print due to the great effort to accommodate sufficiently. Presbyopes must never be allowed to select their own lenses, as almost invariably they select them too strong. It should be clearly understood that Pb. is not a deficiency of refractive power in the eye, but a loss of power of accommodation, a loss of dynamic refraction, so that the eye no longer has the ability to increase its own refraction, by which it is enabled to focus divergent rays of light from near objects upon the retina. As age advances this power of accommodation becomes gradually less and less, until, at about the age of seventy, it is altogether lost.

For continuous close work we cannot *maintain* comfortable vision when using the full amplitude of accommodation, nature demanding that some force shall be reserved. When persons begin to maintain accommodation equal to more than *one half* of their available amplitude they experience uncomfortable sensations caused by using their eyes under such conditions.

To read at a distance of 16 inches from the eyes requires 2·50 D. of accommodation, consequently it follows, that unless a person has an amplitude of accommodation of about 5·00 D. he will experience discomfort if he reads for any length of time. This is precisely what occurs in presbyopia, which exists in most eyes over forty-five years of age, in some people becoming manifest a few years earlier, and in others a little later, the precise age being indefinite, and varying with the physical condition. We may consider that presbyopia is present *when it is no longer possible to do close work easily at the usual distance*, or it may be said, similarly, that presbyopia is established when the p.p. does not correspond to an amplitude of accommodation double in amount to the accommodation required at the reading or working distance. More dogmatically still, we may say that in ordinary cases presbyopia is determined when the p.p. is found to have receded beyond 8 or 9 inches. Tests for presbyopia are made with the glasses on which correct the refraction, and both eyes are tested together, the proper correction being that pair of added *plus* sphericals which makes vision better at the reading or working distance than either nearer to or further away. A good means of determining the lenses required is to find the binocular p.p. and note the corresponding amplitude of accommodation, taking half of its amount to allow the client in use, then, having ascertained the distance of the desired reading (or working) point from the eyes, to note the refraction required for divergent light from that point, and subtract from that amount the accommodation which the client is to be allowed to use. The difference will give the glass required to furnish the necessary refraction and *still allow the client to hold half his amplitude in reserve.*

Another method is to place before the client the card of hand test-types (arranged after Snellen's) and find the smallest type legible at the natural distance. The figures printed in the margin of the card opposite to the type selected will indicate approximately the correction required. With these lenses the No. 1 small type should be legible. The client's special attention is then directed to the No. 3 type, which is the size of ordinary newspaper print. This should be found more legible at the natural distance than elsewhere, which can be verified by making with the card a "to and fro" movement of an inch or two on each side of the required reading place. If the No. 3 is found to be improved when further away, then the glasses are too weak; whilst if it is improved when nearer to, then they are too strong, and must be modified accordingly. It should be noted that the No. 1 type is employed in deciding the nearness of the place, and that it should be legible at the reading distance, but the No. 3 type is used for the "to and fro" adjustment. This is a quick and reliable method for fitting old presbyopes, with whom it is frequently a difficult matter, on account of reduced acuity, etc., to measure the p.p. satisfactorily. Glasses for presbyopia, for reading *at 13 inches, will never require to be stronger than 3·00 D.* In fitting for special work the distance must be taken into account, and a lens found by calculation of focal length suitable for the distance and amplitude, but in no case must a lens be given having a focal length shorter than the working distance required.

The lenses added for presbyopia are always plus sphericals, cylinders generally remain the same, and no change is usually made in their power, except in such cases as indicated in Chap. XXII. It happens frequently, of course, that when plus spherical lenses are added to certain kinds of distance glasses transpositions may be made; for example, a person wears for distance, in both eyes,—1·00 D. cyl. ax. 180°, and he requires adding for his Pb., + 2·00 D. spherical. Here, by transposing, we find the equivalent lens, which is + 1·00 D. sph. ◯ + 1·00 D. cyl. ax. 90°, although + 2·00 D. sph. ◯ − 1·00 D. cyl. ax. 180° may be preferable.

When presbyopia demands correction, and one pair of lenses will no longer serve both far and near, two pairs or their equivalent must be used. To obviate the necessity of changing spectacles, and the use of other unsatisfactory makeshifts, bi-focal lenses are recommended. These combine both distance and reading glasses within the same eye-wire. These lenses are obtainable in many forms, e.g., such as the split, solid, fused, perfection, and cemented varieties.

Of these the "cemented" are the simplest, and most easily manageable along with cylindrical combinations, and when alterations are required they are less costly than with some of the other varieties. The method of manufacture is to employ a full sized lens for the distance correction, and to cement upon it at a lower part an additional thin wafer of glass ground to the requisite curvature giving the additional power for reading. As a rule the wafers are cemented to the inner surface of the lens, although they are often met with otherwise. The cement employed for the purpose is known as Canada balsam, usually dissolved in a solvent such as benzol or xylol, when it is much easier manipulated than when used alone. In very thin films it is practically colourless and invisible, whilst its index of refraction coincides closely with that of glass.

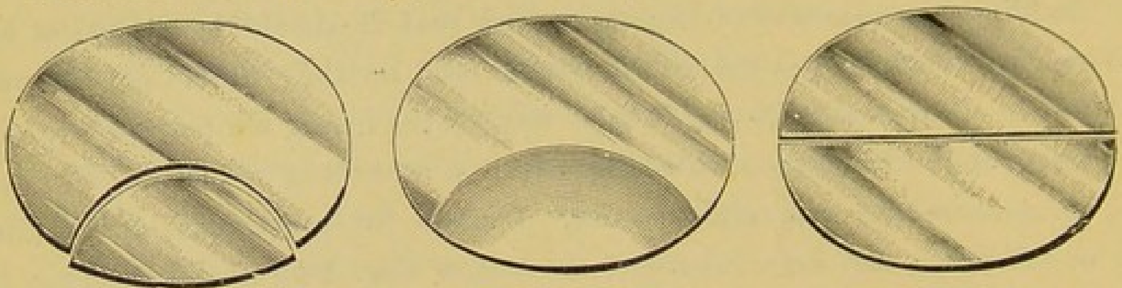


Fig. 103.

Perfection bi-focal. Cemented bi-focal. Straight slit bi-focal.

The chief things to observe, when supplying cemented bi-focals, are that the wafers shall be of suitable size, shape, and thickness, that they shall have neat and cleanly cut edges, that the inner surface shall be in close contact with the surface of the large lens, that the cement shall be clear, well set, and free from air bubbles, and last, that the optical centre of the combined lenses shall be located in the correct position for reading.

The wafer should be so cemented that its top edge shall fall *at least* 2 mm. below the centre of the distance glass. The maker of the lenses arranges to give the wafer such an amount of downward decentration as will, when opposed to the upward decentration of the distance lens, afford a correct position to the optical centre of the combination. The optician should always locate both the centres so as to verify for himself their suitability in position. For spherical combinations periscopic distance lenses are employed with a definite amount of concavity (usually = 1·25 D.), and bi. cx. wafers, ground to a thin edge, and properly decentered, are cemented thereto. With cylindrical lenses and sphero-cyls., wafers will usually have to be specially worked to fit the curvature upon which they have to be attached, and are more expensive. In cases of astigmatism with cylinder axes at oblique meridians cemented bi-focal lenses are inadvisable because of the inevitable prismatic effect.

The "straight slit" and "perfection" bi-focals can be employed to obviate this effect, because, in both, the distance and reading portions are made from separate lenses, and cylinders with oblique axes can be correctly centered. The former, also called the Franklin bi-focal, is not very generally used, because it cuts off too much of the "distance" field of view, and is apt to cause serious trouble when the wearer is ascending stairs, or even in walking, because vision for such is not possible through any part of the lower portion. This objection is overcome in the second type, in which the lower lens is grooved along its curve in contact with the upper one, which has a bevel upon it fitting into the groove, so preventing movement of one edge against the other. The horns of the upper crescent allow for oblique downward vision. The lenses may be made in a light form by special working, and are never expensive.

Similar in appearance is the "down-curve" solid, or "Unibifocal" lens, which, as its name indicates, is made from one piece of glass. It is very neat and light, but in its best forms is expensive, especially when the reading correction needs some alteration as often happens. This applies also to the various combined lenses which are now made, the reading portion being inset bodily into the distance lens, the extra power being obtained by using glass of a higher index of refraction. This may be fitted into a corresponding depression upon one surface and cemented, or it may be electrically fused thereto, forming a single solid piece. The inner surface is then ground so as to give an identical curvature over the whole. The latest and best of these is the patented Kryptok lens.

In all these cases it is well to have a cement variety made up, of the same shape, etc., for trial by wearing before the more expensive lens is ordered.

Bi-focals are most suitable for persons who walk with head erect, and are likewise very suitable for those who are hyperopic over 2·00 or 2·50 D., in addition to being presbyopic. In cases of considerable astigmatism they are not often a success, and even when sphericals only are needed there are many elderly people who, not having worn them before, find them intolerable, and so marked is this that few will accept them over the age of 60. If there is a moderately large amount of H. and a low degree of As. (1·50 D. or under), then they are usually very acceptable, but along with prisms they are always a very doubtful experiment. Bi-focals should not be fitted in high myopia, nor in cases of anisometropia if there be asthenopia.

When upon the face bi-focal lenses should be set low, as for reading, with the top edge of the wafer or inset about 2 to 3 mm. below the wearer's pupil when his gaze is fixed upon the horizon. They should also be set a little further out from the eyes (about 3 mm.) than ordinary glasses, and the frames should always have the joints angled suitably (usually from 10° to

20° will suffice). Some makers decenter the large lens slightly upward, but theoretically the correct position for the optical centre is, for the upper lens, in the geometrical centre of the glass, and, for the lower, half way vertically between its top and bottom edges, and 2·5 mm. to the nasal side of the vertical meridian.

There is one disadvantage which applies to nearly every type of bi-focal, equally with spectacles made for near work only and which have not the lenses angled from the vertical when in front of the eyes. To explain this it is necessary briefly to consider the effect of oblique refraction, which may readily be seen by tilting a spherical lens in front of the eye and neutralizing it. The result will be a sphero-cylinder with axis at right angles to the meridian of the tilting (or in the same position as the axis of rotation). The effect of tilting a + 1 D. lens at various angles is shown in the Tables at the end of the book, but its importance is seen by the fact that, as the angle of tilting increases, the cylindricity increases, roughly as the square of the proportion of angular increment. Thus a + 3 D. lens angled 10°, becomes + 3·029 D. Sph. ○ + ·095 D. Cyl., and when angled 20° is + 3·12 D. Sph. ○ + ·413 D. Cyl. From these figures it is evident that, unless the lenses are angled for reading, the result may prove very unsatisfactory, either neutralizing, partially or entirely, the cylindrical effect intended, or else increasing it correspondingly.

Old wafers may be easily removed from lenses by heat cautiously applied, or by the application of benzol. If they are to be re-cemented all the old balsam should be cleaned off by benzol, meth. spirit, or turpentine. Air or moisture, perspiration or grease, penetrating between the lenses spoils their appearance and utility, and when such occurs they should be re-cemented.

Summary :—

(*a*) Presbyopia cannot be corrected until the condition of the refraction is known.

(*b*) It is estimated with the distance glasses on and both eyes in use together.

(*c*) For its correction pairs of suitable plus spherical lenses are added to the distance glasses.

(*d*) No change is usually made in the power of cylindrical lenses for presbyopia.

(*e*) Bi-focal lenses are not suitable for all clients, and always need special care in fitting and centering.

Chapter XL.

CORRECTIONS AND THEIR MODIFICATIONS.

IT frequently happens that lenses supplied after careful tests have been made, and which are *theoretically correct* (so far as can be ascertained at the time), are practically not a success. Now, as comfort is the great desideratum in the use of glasses, it follows that any correction which does not give this, or which produces discomfort where none existed previously, is a failure *practically*.

The human eye is not a mere optical instrument, and the correction of defective vision by lenses is not always a simple optical problem. We have to consider not only mathematical optics, but also physiological conditions, and often a personal element. Some consideration, first, of exceptional cases, such as occur in hyperopia, may be useful. Here we have the rule, that the proper correction for hyperopia is the *strongest* pair of plus sph. lenses giving the best obtainable sight. We will consider how this rule works out. In young people, with a large amount of latent defect, we find that even the strongest lenses, fitted subjectively at a first visit, are unsatisfactory. Frequently with these the No. 1 Jaeger's type *cannot be read.* Here is a need for stronger lenses for distance, and it cannot be too often insisted upon, that in *ordinary* hyperopic cases in persons under forty years of age two pairs of glasses are *never required.* If therefore No. 1 small type cannot be read with the lenses fitted, it shows either that they are not strong enough, and some defect is still latent, or that there is reduced visual acuity. The proper course is to tell the client to wear them constantly for three weeks and then to return. He may then (owing to accommodation being more fully relaxed) be fitted with stronger lenses. If, however, No. 1 type (Jaeger) is legible with the glasses, but V. is still not really comfortable for close work, the same course should be again pursued, the client returning once or twice for stronger distance lenses until perfect comfort in near V. is achieved. In persons over thirty years of age accommodation should not be unduly repressed, and lenses fitted monocularly will be more comfortable in wear than those which include binocular additions. For clients over fifty or fifty-five years the proper correction in H. is the weakest plus sph. lens giving the best obtainable sight. In hyperopia the glasses must always be worn for close work. They must be worn constantly if they improve distant V. or give thereby relief to headaches or asthenopia, and also in every case of squint or anisometropia. With squint the glasses must be the fullest possible correction, and particular regard must be paid to the exact centering of the lenses. After an operation for squint the corrective lenses are needed for constant wear even more emphatically, if possible, than before.

In myopia, the younger the person the more important it is not to fit quite a full correction. If the defect does not exceed 2·50 D. no glasses are needed for close work, *unless there be anisometropia.* No harm, however, will be done if they are used. In myopia of over 2·50 D. it is more important to have glasses for close work than for distance, so as to prevent it being done too close to the eyes. In medium grades of myopia, if with the distance glasses on the No. 1 Jaeger's small type is legible at the proper distance, then 0·50 D. or 0·25 D. may be deducted from them, and the remaining power given for *constant use.* If the No. 1 type is not legible with the distance glasses, they must be reduced in strength until it is, and the resultant lenses given for constant use, without any further reduction. In high myopia glasses are imperative for all close work, to prevent it from being done so near as to be injurious to the sight. The lenses in these cases are usually considerably weaker than the measure of the defect. In very high myopia the glasses should be fitted as if for close work only, quite regardless of distant vision, and they must always be those lenses which remove the working point as far away as conveniently possible.

Reviewing the modifications to be made in myopic corrections, we may consider that in all medium degrees of M., where the distance glasses are found to serve well for close work, we should reduce them from 0·25 to 1·00 D., according to age of client, amount of defect, nature of occupation, etc., and should order the glasses to be worn constantly. Where the distance glasses do *not* allow of the No. 1 type being easily read we should reduce them from 1·00 to 3·00 D., and let these glasses be worn constantly, always reducing the distance glasses as little as possible compatible with achieving the object in view. The reduction for close work must never be unnecessarily great in amount, and in the really worst cases should not exceed 4·00 to 4·50 D., and will usually not exceed 3·00 D.

High myopia must be regarded as a diseased condition, and myopia which increases after 20 years of age is of a dangerous type, and needs the care of an oculist. No optician should keep any case of myopia under optical treatment if he observes an increase in its amount of over 1·00 D. If clear distant V. also is essential to those who have thus been undercorrected for close work, then a second pair of glasses may be supplied for *occasional* distant use. A full correction of myopia may be given if the defect is not over 3·00 D., and the client is of adult age, but young people, and all with high degrees of myopia, *must be undercorrected*. In myopia the glasses for close work are not given to improve vision, but to remove further away the working close point, and so relieve injurious strain. A properly fitted myopic correction is usually a fairly permanent one for life, myopes of over 4·00 D. *never* becoming presbyopic in the sense of needing plus lenses for reading or other close work.

In Chapter XI., in accordance with usage, a table of amplitudes of acc. was given, and so far we have assumed that these amplitudes were constant for the various defects, as for Emm. As, however, muscles generally increase with exercise, we might fairly assume that in H. of low degree the amplitude of acc. would be in excess of that for Emm. *at the same age*, and that in low M. it would be deficient. Careful research has shown this to be the case, the differences commencing at about the tenth year, and attaining a maximum at about twenty to twenty-five years, the variation between H. and Emm. then being about ·75 D. and between Emm. and M. about 1·25 D. Wearing the correction annuls the differences, which seems to prove that they are due to the greater and less exercise respectively of the ciliary muscle in H. and M. compared with Emm. In estimating amplitudes it is well to remember this, and take into account also not only the static refraction but the occupation and general health.

With astigmatism the aim should be to give, generally speaking, the strongest plus, or the weakest minus cylinder that makes all lines equally black. Cylindrical lenses are not usually altered for close work, but occasionally cylinders comfortable for distant V. are not so for near V., and cannot be tolerated. In astigmatism we expect, in most cases, to find the cylinder axes in the two eyes reasonably symmetrical with each other. They are usually found with axes R. and L. similar in direction to one of the following pairs :—

| | . \ / . = . / \ . | / . | \ .

These apply to congeneric corrections, but if they are contrageneric then opposites may occur. Distortion produced by cylindrical lenses usually disappears with wear, if persisted in, and newly fitted glasses are rarely perfectly comfortable at first, the proper effects not being experienced for about 14 days. If the distortion produced by the lenses does not very shortly disappear, the effect of slightly reducing the power of the cylinders may be tried, or a slight rotation of the axes either nearer to, or further from the vertical may be resorted to.

Of all conditions where corrections may require modification anisometropia is the most frequent, the form known as antimetropia, where the refraction of the two eyes is different in character, hyperopic and myopic (for R and L or L and R) as a whole, or in some meridian, being especially troublesome. Anisometropia should properly only be considered a defect when the differences are sufficiently great to cause trouble, which may vary from slight asthenopia to loss of binocular vision, and these differences have different values according to the amount of defect existing. For instance, eyes myopic 1 D. and 3 D. respectively are anisometropic, so far as trouble is concerned, much more than are those of 8 D. and 10 D. respectively, because the blurring of vision in the latter is fairly equal, and vision is never good, whereas, in the former, vision at the far point of each eye, a position frequently in evidence, may be excellent,but the two eyes can never have the same definition of retinal image at the same time, and accommodation must be very troublesome within 20 inches from the eye.

It seems most probable that anisometropic eyes, with very rare exceptions, obtain such vision as they have by using one distinct retinal image, that of the better eye, in conjunction with the more or less blurred one of its fellow, to obtain stereoscopic vision. In some forms of astigmatism this blurring of an object by both eyes, each in a different direction, may allow the retinal images to be combined with a certain amount of satisfaction, and when the correcting cylinders are given, the client, seeing the well-defined figure by means of slightly differently shaped images, may be quite unable, at first, to properly fuse them.

The question of accommodation by anisometropes is a difficult one, but most authorities seem to agree that, where visual acuity in the two eyes is fairly equal the amount exercised is generally governed by that eye requiring the exertion of the less amount, and thus in correction it is a good plan, generally, to modify the lenses before the eyes, with a view to equalizing the amount necessary for vision in close work, by this means also restoring the harmony of accommodation and convergence.

Vision in anisometropia may be (1) binocular, (2) monocular and alternate, (3) monocular, with exclusion of the other eye. It does not follow that in the second case the person will come for correction, because it is possible that the one eye may have good distant vision and the other may be myopic 3 D. or 4 D. and so get good near vision, but there will be no stereoscopic vision. When lenses are provided, of opposite signs, and so called contrageneric, there is likely to be trouble whenever the eyes move from a primary position to a distant secondary one, because the convex lens will be acting as a prism, base in, or out, according to the direction of movement, and the concave also, and this prismatic effect will be combined, in effect, with a lens equal to the algebraic difference, for instance + 2·5 D. and − 3 D. will result in a 5 D. lens decentered accordingly. The subject is so large that a few hints must suffice.

In anisometropia, glasses fitted to each eye separately can be prescribed if it is found that distant vision is comfortable with them, and the p.p. of the two eyes are at the same distance away. If not, the difference between the two glasses must be reduced, so that if both the lenses are plus, or both are minus, the stronger glass only is reduced, but if it happens that one is plus and the other is minus, then each should be reduced, but principally the stronger lens, the worse eye always being considered secondary to the better one.

In ordinary cases of anisometropia in adults, a difference between the two eyes of 1·50 D. is usually the greatest amount that will bear correction with comfort, though this rule is very flexible. If the visual acuity of the two eyes is about equal, the client will often accept a proper correction, because there will be similar retinal images; on the other hand, if the difference is great, it may be better and more comfortable for the client if he has a *pair* of glasses to suit the good eye, unless contrary to what the refraction of the more defective eye demands.

Where there is a high degree of defect in both eyes it is usual to find that a fuller correction of difference between two eyes can be borne than in lower degrees. For people over fifty to fifty-five years, who have not previously worn any correction, we should not usually supply lenses with a greater difference in the powers than 0·75 or 1·00 D. No hard and fast rule can, however, be followed, careful consideration of all the conditions being required in each individual case.

The aim throughout, in anisometropia, should be to give comfortable binocular vision, together with as perfect an equalisation of the near points as possible. In high degrees equalisation of the near points can hardly be hoped for, but in the lower degrees, to insure a proper correction and comfort, it is absolutely essential that the p.p. are the same in both eyes. If not, it is necessary to revise the results, re-test, and equalize. In H. with esophoria, we must give the strongest plus lenses, but if in doubt we endeavour rather to under correct than over correct, even in this condition. In H. with exophoria we should give weaker plus lenses, and they may need to be very considerably weaker than the ordinary correction. In esophoric myopia we reduce the distance glasses for reading, so that *no accommodation* is used at the working distance, and with this condition clients often prefer not to wear glasses constantly. In M. where there is exophoria, we allow accommodation to be used for close work, and give minus lenses pretty full, subject to the usual restrictions. In H. with esophoria, and in M. with exophoria, if a full correction of refraction fails to produce comfort and V. remains painful, then the lenses may be combined with suitable prisms. In H. with exophoria, and M. with esophoria, if a low correction fails to allow V. to be possible with comfort, then the lenses must be combined with prisms. Such cases are rare. Occasionally, persons who are hyperopic with exophoria are found wearing weak minus lenses with perfect satisfaction, because by putting a further tax on accommodation they easily overcome the concaves; at the same time these stimulate convergence and so give comfort. When the accommodative strain becomes too great discomfort arises, and the error in the lenses is revealed.

Summarizing, we may say that esophoria requires either stronger convex lenses, weaker concaves, or prisms with bases out. Whereas exophoria requires weaker convex lenses, stronger concaves, or prisms bases in. In exophoria we can either apply lenses to increase accommodative effort, or prisms to reduce the effort of convergence, whilst in esophoria we can apply lenses to decrease accommodative effort, or prisms to relieve the strain on the external recti. Exophoria is generally indicated when the p.p. is found nearer in binocular than in monocular vision.

Divergent strabismus from myopia may often be cured by the use of corrective lenses, and proper training of the deviating eye. This form of squint usually causes no inconvenience or asthenopia; the sight also is often fairly good in the deviating eye, and rarely is there any diplopia, but if so, it is generally at the commencement of the squinting condition. A general rule in such cases is, if the myopia is under 6·00 D., to give (with the usual safeguards) a full correction, and if over 6·00 D. to give the fullest correction possible compatible with comfort in near vision.

With regard to the wearing of corrections for astigmatism, theoretically the cylindrical lenses should be worn constantly, but in simple astigmatism of low degree the rule is very elastic.

In high degrees of defect reduced acuity must be expected, but often, after the corrective lenses have been worn for some time, the acuteness of vision becomes very greatly improved. In young people all the astigmatism up to 2·50 or 3·00 D. should be corrected, above that it is *sometimes* wise to correct only about two-thirds of it, especially in myopic forms, where frequently an exact correction is difficult or impossible to fit. Young people with seeming myopic astigmatism are often exerting accommodation equal to the defect, and *really need plus cylinders with axes reversed.*

There are certain modifications sometimes necessary after a correction has been determined, which are caused by the habit or employment of a client, and which do not follow from the exact amount of defect disclosed. Amongst these are alterations in the form of a lens for certain purposes, and the alteration of power due to the position of lens in front of the eye, or the distance of the object viewed. In the first of these we must distinguish between objects viewed through the centre of a lens, and those seen, by turning the eyes, through parts nearer the periphery, and we will call these portions of the *field of view* central and peripheral.

With ordinary forms of double convex lenses vision through the margins is much more indistinct than through the centre, because it is oblique, and also the lens is of slightly different power, with a prismatic element. To counteract this meniscus lenses have been employed in which the inner curvature varies from that of the ordinary periscopic (about – 1·25 D. sph.) to those devised by Percival and others, which have inner curvatures of –5 D. and upwards. Corresponding to these are the toroidal (toric) lenses, which are always plano or sphero-cylindrical in effect, the one surface being a tore (see page 151) and the other a spherical curve.

It is very difficult to lay down exact rules for the employment of such lenses, and each case must be judged upon its merits, the indiscriminate use of them being exceedingly unwise, because they have disadvantages as well as advantages. We may, however, give general illustrations of their utility and the reverse.

There are many cases, such as those of architects and surveyors, where maps and plans have to be examined and measured, and in estimating distances most accurately it is noteworthy that the best results are obtained when the eyes only are moved, the head being kept steady, so that with periscopic lenses, where vision is good and lines are not unduly distorted at the periphery such people are likely to get a distinct advantage. With artists, too, the same thing may occur, and many instances are on record where musicians have derived great advantages.

There are, however, limitations, and it is found that above medium powers such lenses become a source of trouble, especially in toric form. Here, contrary to what has been believed, the images of objects formed on the highly curved surfaces of the lens have often been a source of great annoyance, and any motion of the eye from one position to another has, in some cases, caused an apparent swirl in the field of vision. Where there is doubt of success it is well to order sphero cylinders in contrageneric form, and such a lens as + 4 D. sph. ⊂ + 3 D. cyl. Ax. V. might with advantage be given as + 7 D. sph. ⊂ – 3 D. cyl. Ax. H. (See also Chap. XLVI.)

Deep curve sph., and sph.-cyl. lenses are very often useful in fitting presbyopes with cemented bi-focals, because the effect of angling is given to the reading portion.

In Chap. XXII. reference was made to the influence of position of the object on the effect of high power lenses, the cylindrical effect of a sphero-cylinder being increased thereby. We have also seen in Chap. XXXIX. that, unless a lens is angled for reading a cylindrical effect is also produced, so that, with astigmatic presbyopes these two factors have to be considered, because the cylindrical elements added may, in effect, create a spherical, or on the other hand, they may reinforce each other, and so produce an equivalent lens quite different from what was intended. Generally speaking, when the axes of correcting cyls. are with the rule the effect will not be injurious in **H. As.** or **M. As.**, but when the axes are against the rule the cylindricity added because of nearness of the object, and that caused by tilting will often prove very troublesome.

Summary :—

(*a*) In **H.** separate glasses for reading and distance are not needed up to forty years of age.

(*b*) In **M.** over 2·50 D., glasses for near work are very essential.

(*c*) High myopes and myopic children *must be under corrected.*

(*d*) Squint cases (**H.** and **M.**) need very fullest corrections, and well centered lenses.

(*e*) Muscular imbalance renders modification of lenses necessary.

(*f*) If modified corrections fail to give comfort, then prisms may be added.

(*g*) Apparent myopic astigmatism in young people may be very misleading.

CHAPTER XLI.

ASTHENOPIA AND ITS SIGNIFICANCE.

"ASTHENOPIA manifests itself as a fatigue system that soon appears after near vision. The eye is not apparently diseased, and it is not painful, even when it is. Visual acuity and the ocular movements are both normal. Distant V. is considered perfect, but reading, writing, &c., cause a sensation of tension over the eyes."

These are the words of Donders, the first who gave a well defined explanation of asthenopia. Since his day the subject has been investigated and elaborated until eye-strain, which is merely another name for asthenopia, has been considered by various writers to be the cause of nearly every organic trouble. The explanation given by Donders is typical of a certain number of cases, but it is incomplete, although the main point, the presence of a fatigue system is characteristic of nearly all forms of the trouble, this being manifest as headache, a feeling of heaviness, or general lassitude. Asthenopia, even when proved to be caused by some particular defect, should rather be regarded as a product of some imbalance or lack of co-ordination of nervous impulses, which has been caused by the particular condition or defect of the ocular organism, and that this is so seems extremely probable when we consider two constantly recurring states with which it is associated. In the first of these what stands out prominently is the fact that a low degree of error, or a comparatively trivial difference causes much more trouble than a high degree of defect, which seems to point to the conclusion that when an error or difference is superable, being within the power of the eye to annul it, there is always an effort made to do so, whereas when the defect is insuperable there is not the same inducement to effort, and new associations are formed. The second state which is prevalent with asthenopia is a condition of nervous excitability or irritation above the normal.

The division into sections is convenient only, because there is always the probability of a certain case partaking of the nature of two or more of the sections. Those generally recognised are : — 1. Accommodative.

2. Muscular. 3. Iritic. 4. Retinal. 5. Reflex. With the two last classes the optician is not competent to deal, and iritic cases are not well defined and far from numerous, the cause being generally diagnosed by a process of elimination, unless the defect is righted by the slight over-correction of a very trivial amount of hyperopia.

The accommodative asthenopia of Donders is somewhat of a misnomer, for he says :—"I have shown that asthenopia is not an accommodative anomaly, but that it is one of refraction, namely, a definite degree of H." It is thus the shortage of refraction so to speak, the amount of H, as evidenced by the position of the far point of the eye, which causes the accommodation to be exercised by an amount more than is indicated by the distance at which work is held, and which induces a greater demand for the linked function of convergence than is necessary. Incipient presbyopia is often accompanied by asthenopia in the hyperopic eye for this reason. Bull and others place the trouble in the external ocular muscles rather than in the ciliary, and it is possible that this is so in some cases.

It is rare to find asthenopia with high degrees of hyperopia in children, because the differences in the exercise of accommodation and convergence are so great that either new relations entirely are formed, or else the effort is abandoned and squint results. There is one matter of considerable importance in this connection, the exact appreciation of which necessitates a careful study of Chap. XXXVII, where muscular imbalance and the importance of latent defects were treated. It must be evident that some effort is necessary for the eyes to fuse two images of the same object for proper binocular vision, when there is a latent defect in the musculature, and this effort cannot be detected until the muscles are tested and the defect unmasked. The desire for binocular vision in these cases has been termed the *fusion sense*, and the strength of this to overcome the difference, which has also been called the *fusion supplement*, may vary much in different people. In hyperopia, where undue exercise of accommodation stimulates convergence, and so causes esophoria, the fusion supplement must be greater than in emmetropia, and the greater the fusion supplement the greater the fatigue of the internal recti muscles. Also most myopes have the power of using convergence in excess of accommodation, because they must converge for all near objects, but they do not accommodate unless the object be within their near point. The liability to strain is greater than in emmetropia, as the fusion supplement is greater, so that asthenopia may be present with myopia, and is then of the muscular type.

We may summarize to some extent, from what has been already written, and state that asthenopia in hyperopic cases is most frequently caused by a discrepancy between the amounts of accommodation and convergence exercised, and where it exists in youth the immediate cause of the trouble is likely to be the external muscles, whereas, at a later age, strain of the ciliary muscle may be the factor, as when presbyopia is approaching. In myopia the external muscles must be regarded as the seat of the immediate cause, but in all instances the effort—that peculiar combination of strong motive and insufficiency or weakness—is the underlying cause of most of these troubles.

Astigmatism of low degree is very productive of asthenopic symptoms, dizziness and confusion often being very pronounced. There seems to be little doubt but what the astigmat with a high degree of error is content to get the best vision possible with the blurred retinal images, and the condition of strain, the same effort of which we have already spoken, is generally absent. Where, however, the blurring of certain lines is much less than this, and others are distinct, there seems to be an effort to equalize the definition, and this often in myopic as well as hyperopic astigmatism. Much has been written of sectional accommodation of the crystalline lens, by which low degrees of error may be overcome, but the proof in favour of it is by no means convincing, especially as the result may be accounted for in other ways. The great probability seems to be that the position of the indistinct lines causes the trouble, for in hyperopic astigmatism with the rule vertical lines will be blurred, and in myopic astigmatism with the rule horizontal lines will be indistinct. In distant vision vertical lines play a predominant part, and the diffusion circles upon the retina of the hyperopic astigmat cause confusion, which creates a desire for distinct vision, this in turn creating an effort to overcome the trouble. This is the type of asthenopia which is so common, and where corrections averaging + ·50 D. sph. ⊃ + ·50 D. cyl. axis V. are so numerous. In myopic astigmatism, on the other hand, especially of the "simple" variety, the blurring of the horizontal lines causes an effort to equalize the meridians when near work is done, provided of course that the defect is of low degree, and so we may account for the prevalent asthenopia of students with simple myopic astigmatism.

These troubles may sometimes arise from the action of the external muscles in an endeavour to correct the defect, and where astigmatic accommodation seems present a traction upon the cornea may possibly account for it. When the faulty meridians are oblique trouble is frequent, and Savage has suggested that the oblique muscles may be an immediate cause, in consequence of their effort to rotate the eye into a position which would obliterate the distortion. That such rotation actually does occur in some eyes may be seen by his device, which consists of a trial frame, having one cell empty and the other containing a double prism, an arrangement of two prisms, with bases together, ground upon one glass, the line dividing the prisms being placed in a horizontal position, so that an object viewed through them is doubled in a vertical direction. When the trial frame is placed upon the face three images of a horizontal arrow (printed upon a card) are seen, the one, due to the naked eye being between the two due to the double prism. Where a twisting, or torsion, exists the central arrow is not parallel with the others.

In anisometropia (Chap. XXXIX.) there are several possible causes of asthenopia, some purely muscular, as where the amount of accommodation demanded by the two eyes to view objects at a certain distance is different, and others due to the differences in size of the retinal images (Chap. XXII.), either actual or apparent, because of the greater blurring of one of them. In the first case, when the difference in refraction is great, no effort is made, and one eye is used for distant and the other for near vision, especially where antimetropia exists. In the second group also the trouble is more probable with slight differences, because the images, as formed in the most faulty eye, are often suppressed mentally, and are not used so far as definition is concerned. In some cases an apparently normal state may exist for a long time, the eyes having become accustomed to the particular condition, but any great demand upon the eyes may cause the trouble to become manifest. That inequality of images, and also distortion, may produce asthenopia is evident when we consider what annoyance sphero-cylindrical lenses with inclined axes may cause when first worn, and we also see that the eyes may adapt themselves to the new conditions in many cases by perseverance. Similarly, trouble arises occasionally where an eye, previously the worse one, is, after correction, put upon an equality, for visual acuity, with its fellow.

Prentice has described an iritic asthenopia, and maintains that the trouble is quite as likely to be caused by an incorrect size of pupil as by an error of accommodation, and there is no doubt that many hyperopes have small pupils, just as myopes often have large ones, the connection between the contraction of the ciliary muscle and the sphincter of the iris being deduced from this. In further confirmation he points out that, when very low power lenses are used to relieve asthenopia, the pupils are comparatively large. The provision of the necessary lens for the correction of the defect, as in all other varieties, generally affords complete satisfaction.

Summary:—

(*a*) Asthenopia manifests itself as a fatigue symptom.

(*b*) Actual pain is rarely present.

(*c*) Its fundamental cause must be regarded as a nervous one.

(*d*) Ocular effort is a combination of strong motive and weakness or insufficiency.

(*e*) Asthenopia may be concurrent with any variety of defect, or even with emmetropia.

Chapter XLII.

FACIAL MEASUREMENT AND FRAME FITTING.

TO correctly measure the face for a spectacle frame fitting accurately in all respects necessitates a greater number of details than for any type of folder or clip, but there is one measurement common to every kind of frame,—the interpupillary distance (usually written P.D.), intended to express the exact measurement of the distance between the visual axes of the two eyes, where *theoretically* they pass into the optical centres of the lenses placed before them.

This estimation is the first consideration for the purpose in view, and we must find some corresponding points on the surface of each eye which will enable exact measurements to be taken. The points of exit of the visual axes are the precise points, but their determination is far too complicated a procedure. The pupillary margins will not do, for they vary in position too frequently ; but the *outer margins of the irides* are fixed, and are suitable for our purpose. Many devices have been applied to this measurement, but with due care, a millimetre or inch rule should suffice.

The client must be placed with the head erect and the eyes in the primary position (Chap. X.), vision being fixed on a distant object. For this purpose a standing or seated position may be assumed, so arranged as to obviate bright light falling directly on the face, the back being towards the window or other source of bright light. This is necessary on account of possible reflex action, for, given contraction of the pupil, slight convergence may follow, through these being, to some extent, "linked functions," an alteration of the P.D. resulting. The observer should stand so that the eyes to be measured are directed towards a distant point over his left shoulder, and the distance between the nasal margin of the right and the temporal margin of the left iris measured by a rule or scale held edge down in a horizontal position. The result will be a trifle under the real P.D. owing to the error of the parallax, but this is so slight as to be negligible if the *full* measurement is taken.

In cases of eyes asymmetrically placed with respect to the nose it is necessary to know the extent of the unequal development. The actual P.D. must be noted, and also the centre of the crest of the nose, because in bridge fitting this must be reckoned with. In cases of inequality of height the rule should still be kept horizontal for measuring the distance, and an estimate formed of the difference in height, by placing the rule so that its edge crosses the pupillary centre of the higher placed eye, leaving the lower pupil visible. The difference between the pupillary centres is allowed for in the positions of the two lenses, the long axis of the one being placed just so much above the long axis of the other.

Difficulty may also arise in cases of squint, the principle of measuring in all such defects being the covering of the eyes separately by the hollow of the hand, so as to allow each eye in turn to fix the object. The measurements must be taken from the centre of the crest of the nose or "median line" as in the former case. If the squinting eye is so bad that it will not fix at all, then the centre of the pupil of the good one must be taken from the median line, and a similar distance allowed on the other side for the other eye.

If a spectacle is to be fitted attention must next be devoted to measurements for the bridge, the type required being decided beforehand. For the X. or reversible W., merely projection, or distance of the *inner* surface from the eye-wires is necessary. For the K. bridge, height above the centre line of the joints, and projection from the eye-wires must be taken.

Certain adjustable measuring frames, in which a bridge may be raised or lowered, with an additional inward and outward movement, have been designed, but with many of these the results attained are frequently unsatisfactory when the actual frame made to the details indicated is placed on the face.

A series of trial frames having plano or very weak concave glasses in them may be used, the details of the frame being scratched on by the diamond, or else having flattened and widened ends to the sides, with the same details stamped in brazed letters. In both cases it is well to have cross lines, vertical and horizontal, marked on each glass, indicating the geometrical centre, and affording points for gauging the measurements. Trying one bridge for height and another for projection, the two may be combined, and with a judicious assortment of bridges it is quite possible that a frame may be found which will give the exact combination necessary for many cases.

The crests of some of these trial bridges should be actually on the centre line of the joints, and at least one must be $\frac{1}{16}$th. inch below. Likewise provision must be made of crests flush with the plane of the eye-wires, and also two or more receding from this position, to allow for free movement of long eyelashes. The selection below gives 12 frames, in which H. indicates height above the centre line, and P. the projection from the plane of the eye-wires, the minus sign showing distance below the centre, or recession from the plane referred to.

No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12
H.	-3	0	0	3	3	3	6	6	6	9	9	12 mm.
P.	-2	-2	0	-2	0	3	0	3	5	3	6	3 mm.

The centres need careful selection, for if small frames are used, in many cases they will not fit on persons with broad features. 54 mm. centres should be used for No. 1 and 56 mm. centres for Nos. 2 and 3, 60 mm. and 62 mm. being divided amongst the others.

In fitting a bridge due allowance must be made for the length of the eyelashes to prevent them sweeping the glasses. Knowing the lenses required for the correction of the refraction, allowance must be made for the bulging of a deep convex toward the eye, and also for the extra space which a concave or periscopic may give.

In crank, W., and arch bridges these measurements merely provide for the height of the lenses before the eyes, and their position in front. No account is taken of contour of the nasal surface upon which the bridge is to fit. Contours may be divided into symmetrical and asymmetrical, the latter being difficult to measure in many cases. Suspicion of asymmetry will arise when, during refractive tests, anisometropia is evident, and especially when astigmatism is unequally developed in the two eyes. Bony malformations on the sides of the nose are often co-existent with astigmatism. Marked asymmetry is best dealt with by an impression in modeller's wax, from which a cast may be made in plaster of Paris, or the contour may be taken by a piece of soft lead wire being bent over the nose.

But, presuming symmetry, there are three measurements necessary to ensure contact of the bridge with the skin, so as to avoid undue slackness or pressure. An examination of the human nose will show that there is nearly always a certain position where a spectacle bridge will fit best. Passing from the forehead to the upper cartilaginous portion of this organ there is always a curve, small in very high bridges of the Wellington type, but in the retroussé type, flat and low where the other is prominent, the curve from the forehead will be large. Into the lower part of the small curve of the former, or the upper part of the large curve of the latter the apex of the bridge must fit. Not only so, but the sides of the bridge must be in contact with the sides of the nose to prevent chafing or irritation due to the apex moving about over the bridge of the nose. Pressure on this portion may give trouble through obstruction to the flow of blood in the veins causing redness of the skin.

The formation of a spectacle bridge for fitting the nose is shown in Fig. 104, where CA indicates the radius of the apical circle, DE the base, and AB the depth, the lines from D and E being tangents to the circle.

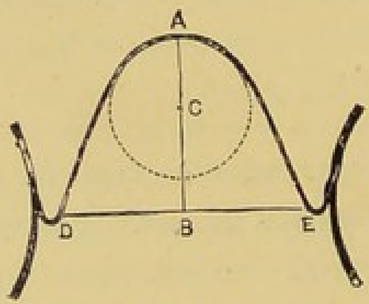


Fig. 104.

This figure is applicable to the measurement of the most diverse bridges. When the base is exactly half the depth the result will be a semi-circle, but it should be noted that it is impossible to have a base less than double the radius, because then the figure would become balloon shaped. Asymmetry can also be expressed by removing the perpendicular, with the apical circle, by as much as is required, from the centre of the base, nearer to D or E.

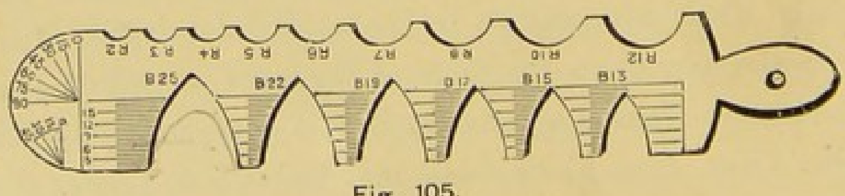


Fig. 105.

Fig. 105 illustrates a scale used for taking the above measurements, the upper series of openings being the arcs of circles of which R specifies the radius in millimetres. These should be tried in succession upon the nose, exactly where the spectacle bridge is to fit.

The apertures upon the other side of the scale are for taking the size of base and depth at the same time, the horizontal lines in millimetres being used to indicate how far the nose sinks into any given opening. This side of the scale should be tried successively for the different base measurements until one is chosen which is exactly suitable for the position of points D and E of Fig. 104, and then the depth of the bridge for that base is read off by the horizontal lines. Taking a base wider or narrower will not affect the contour, because the corresponding depths will be greater and less in proportion. The pointed apex of the opening may be used to detect the presence of asymmetry in the nasal contour.

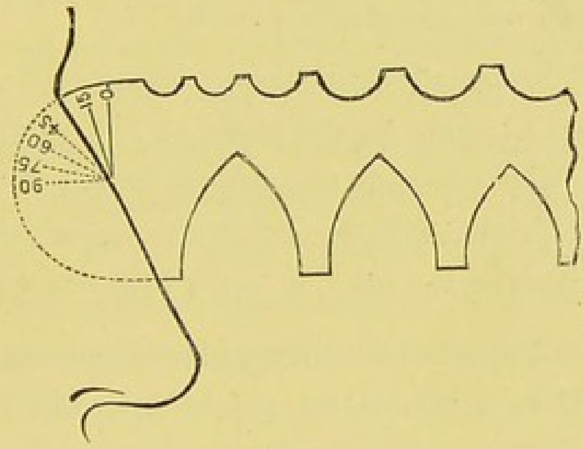


Fig. 106

The protractor scales shown at the end are for measuring the slope of the nose, as illustrated in Fig. 106, the small one being intended for use with children.

In using the scale for taking base and depth care must be exercised that it is held so that the aperture corresponds in slope approximately to what the bridge wire will do in following the outline, and this position will be at right angles to the slope shown on the protractor, a matter further explained in Chap. L.

There are two types of asymmetry of the nose; one of these has just been referred to, and the other is caused by imperfect centering, and where the nose is not centered exactly between the two eyes, the one shank will have to be bent outward to the extent of the difference in distances of the two eyes from the median line of the apex. The pupils must always be the deciding factor in making any adjustment of bridge to suit certain positions of eyewires, never, on any account, should the eyebrows be so used.

For cosmetic reasons a spectacle should be made to fit an asymmetrical face, a procedure better than using a symmetrical frame with lenses decentered, as this would make the defect more apparent. It is also better to specially adjust frames for reading purposes, by having them with 5 mm. less centres and 3 mm. higher bridge, than by decentering the lenses.

The size of eye required must in the majority of cases be determined by the centres, and will be further dealt with in Chap. XLVIII., but the question of deep or shallow ovals must be decided by the peculiarities of each case, a deep oval looking better on the full featured client, and a narrow one on a long thin face. These are matters which no uniform calibration of lenses can adequately provide for.

With a flattened W. bridge of considerable height and small projection, we shall see in Chap. L. that, as the angle of the crest is at 90° with the slope of the sides of the bridge, this cannot be put on the eyewire near the centre line of the joints, without either the upper edge of the flattening cutting into the flesh of the nose, *or extra long shanks being used.*

The larger eyes of tinted spectacles and goggles in general will necessitate care, as less space will be available for the bridge, and in these cases it may be necessary for the geometrical centres to be placed slightly outward from each pupillary centre.

Frontal measurements comprise the distance from pin to pin of the joints, and having ascertained the P.D. and bridge, the rest must be determined by estimation, the *average* difference between P.D. and frontal measurement being about 22 mms. Although outside the details absolutely necessary for securing a correct position of the lenses in front of the eye, it is no exaggeration to say that in the adjustment of the *size of eye* to front, and the fitting of the sides, lies the difference between what we may call the expert and the merely careful worker. No rules whatever can be laid down, as it is entirely a matter of practice and judgment.

Straight sides should go 1 inch past the ear to grip firmly, the bow or inward bending aiding this by slight pressure on the head, and the part from which the bow starts must be determined by the shape of the client's temples; evidently where they are flat the sides will be perfectly straight until they reach the region of the ear. In other cases the temples may be so sunken near the eye that not even with a cocked joint (the shortest possible) will straight sides fit close in to them. Over a certain length such sides may be inarched to a *slight* extent, the distance from the joint being stated at which the ordinary bowing commences. Such cases will arise when the size of the lens cannot be reduced, for obviously, by giving a smaller one the same centres may be retained and yet the fronts will be lessened by the joints coming closer together.

Very full features, on the other hand, will require the sides bowed nearer to the joint, and probably a longer joint also, to allow for the extra space so often found between the outer corner of the eyelids and the margin of the temples of the head. It should be noted that a long joint frequently gives the appearance of a slack fit, unless it is tilted considerably from the plane of the lenses towards the face. In these cases its length must be measured as apparent in the plane of the eyewires, when taking the *frontal* measurements. Curl and cable sides may be bowed slightly at some distance from the joint when necessary, merely to suit the contour of the head; they need no bowing to produce pressure, but to leave them perfectly straight often causes friction on the skin, or else necessitates such a long joint as will give an ugly angular appearance to the front. The best course to pursue in many cases is to open out the sides, or let them back at the joints, which will permit of a smaller joint, with a straight portion of side for about 2 inches near it, after which a slight bending is sometimes advisable.

The correct length of a curl or cable side, from where it is hinged on its joint to the bend, should be the distance between the tips of the eyelashes and the furthermost part of the back of the ear at its junction with the head. Adjustment of the curl which grips the ear will be necessary to make it conform to the shape of that part, a knob at the end of the side being so arranged as to be about 6 mm. to the back of the lobe of the ear, and not visible from the front.

Angling of the joints upon the front of the frame, by which the lenses are tilted for reading or other purposes, is determined by the angle which the sides make *with the perpendicular to the eyewires*. Several factors will influence this, the chief being the position and distance at which work is done, or at which reading matter is held. The natural position assumed by the head must be considered, for clearly the more upright it is the more must the sides be angled to secure correct incidence of rays on the lenses.

Determination of centres applies equally for spectacles, folders and clips, but the two latter forms necessitate measurement of quite different parts of the nasal contour from those taken in bridge specifications. Generally speaking, the plaquets of folders and clips grip a lower, broader, and more irregular surface than that fitted by a spectacle bridge. The distance apart of the plaquets, both at their upper and lower extremities, can only be estimated by trial of certain types, and the length and width of the surface of each between its two extremities must be adapted to the exigencies of each case. With both plaquets movable, adjustment is much easier than with one fixed and the other movable, or with both fixed, but fixed plaquets are the ideal form.

The angle formed by the inclination of plaquets to each other may be measured on the lower half of a circular protractor, divided by horizontal parallel lines 3mm. apart, measured from the centre of the radiating lines. By this means also the distances apart of the various portions can be taken. The amount of "inset" for a plaquet is determined by the lenses being free from contact with the eyelashes, and the amount of the outset of the bar of a clip by the projection of the part of the forehead adjoining and between the eyebrows.

For a better understanding of the whole subject it is advisable that Chapters XLVIII. and L. be considered along with this one.

Summary :—

(*a*) Measurements for P. D. and bridge are the most important details for a spectacle.

(*b*) P. D. is best measured from outer margins of irides, one nasal, the other temporal.

(*c*) To insure absolute fitting of a bridge upon the nose, thereby holding the front in the correct position, six measurements are necessary.

(*d*) Asymmetric faces are best fitted by asymmetric frames.

(*e*) Joints should be angled with a definite purpose, and to a definite extent for that purpose.

Chapter XLIII.

THE MAKING AND KEEPING OF RECORDS.

ONE of the best assets of an optician lies in the records of his refraction cases, for in time such become an exceedingly valuable property, and as records of lenses, visual conditions, facial measurements, frames, charges, exceptions, and so on, they are of the *utmost* importance. No very complicated system of records is essential, rather simplicity and brevity should be aimed at, combined with fulness of all *necessary* information. Perhaps the most important part of the system of record making lies in the index, which should be kept written up to date in each record book as it is used. In addition to the simple index thus afforded in each volume, an extension index comprising the whole of the volumes filled should afterwards be compiled, the names and addresses of clients having precedence over other details, together with the folio number in the record book, and the date of the entry. Briefly then, we may say that whatever system of record keeping is adopted, it is essential that it shall be well, regularly and sufficiently indexed. The order of numbering the books themselves is entirely a matter of individual opinion and expediency, but it is not necessary to label and number the volume actually in use. Only when it is complete, carried forward to the extension index, and put away, does it need to be known for example as "Vol. I." or "Vol. A. :—pp. 1—250." It seems more rational to number the pages consecutively right through the whole series of volumes than to start each book separately with its own first folio. Volume II. should commence numbering its folios where volume I. leaves off, and so on throughout the entire set. Amongst the necessary entries to be made in each record, the client's name, with the surname foremost, comes first, and then his address, together with the occupation and age, if possible. The history of the case may be briefly noted down in addition, if deemed of sufficient importance. Then should come the visual acuity (in naked vision) of both eyes together, and also the vision with the glasses (if any) previously worn. Next, the visual acuity of each eye separately is taken and recorded. If **V.** is fairly good the p.p. of each eye is next taken, but if it is found very defective the pin-hole disc is employed, and the vision obtained thereby recorded. The number of the smallest of Jaeger's type legible is also entered, along with the *furthest* distance from the eye at which it can be read. Next, the best obtainable sight for each eye separately, *with spherical lenses*, is noted, together with the p.p. with the lens before the eye, if vision is now found satisfactory ; once again the smallest Jaeger's type legible is entered, and the *furthest* distance at which it is now read. Binocular additions to lenses are recorded (in brackets), along with the binocular p.p. and acuity of vision. Any astigmatism shown by the ophthalmometer, and the refraction indicated by retinoscopy should be recorded for the two principal meridians, cross lines being drawn to indicate their directions. The results of ophthalmoscopic examinations should be recorded diagrammatically, if there are any abnormal appearances of the fundi. Muscular imbalance, far and near, must have attention, and be recorded by the strength of prism measuring it, the direction of the *prism-base* being carefully specified. The field of vision, when taken, should be graphically shown in the record book, using *at least four* of the chief meridians for each eye. Finally in presbyopia, the amplitude of accommodation should be recorded, the reading or working distance, and the lenses needed. This concludes the record of *tests*. The corrections supplied should now be entered apart from the above, both for distance and for close work.

Full particulars of frames both for distance and for reading should be entered, viz. :—P.D., width of front, character of bridge, height and projection of bridge, base and depth of the same, angle of the crest, size and shape of eyes, character of joints, character of sides, length, bow, and angle of same, and if curl sides, the length from joint to bend, also material, weight, colour, finish, &c., of the frame. FOR PINCE-NEZ AND FOLDERS, details specified in Chap. LII. should be given. If more than one pair of a kind is supplied at the same time, it should be noted, and any special details, such as tinted lenses, pebbles, etc., occurring in any particular spectacle transaction should be mentioned. In making up oculists' prescriptions, a copy of the original should always be entered in the book. The prescription should be *endorsed* by an india rubber stamp, imprinting upon it the optician's name and address, and the date. To this endorsement the number of the record is added in writing. The prescription itself is the client's, and should be returned to him, enclosing it in a neatly printed prescription envelope, bearing name and address. A note should also be made in the record of any cash allowances made from ordinary charges on account of frames, etc., taken in part exchange. In entering powers of lenses the dioptric system should be uniformly adopted, with the regular use of *plus* and *minus* signs to indicate the character of their refraction. Figures should be complete to at least one integer and two decimals in all cases. Thus, for example, we should write + 0·50 D. sph., and not + ·5, or + ·50, as it is not uncommon for records to be made which are afterwards undecipherable even by the very individuals who made them.

When prescriptions are copied, the oculist's name, if known, is entered. With gold frames it is well to record maker's name, quality, and weight, so that an eye can be kept on the wearing qualities of the goods, and no difficulty experienced at any time if duplicates are required. Appended is a schedule for a record which may form a basis upon which a comprehensive record book may be devised, the details of the portion relating to frame measurement being given in Chap. LVIII.

RECORD.

DATE............................ No....................

NAME..

ADDRESS..

HISTORY..

OCCUPATION ....AGE ....

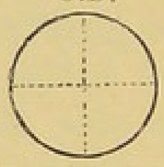
NAKED
VISION O.U.............. (V.O.U. with the lenses worn previously =)
,, O.D.............. P.P............. Pin hole............ Jaeger No..........to......ins.
,, O.S. .... P.P............. Pin hole............ Jaeger No..........to......ins.

VISION OBTAINABLE.
BY SPHERICAL LENSES ALONE } O.D. with............ V.= Jaeger............ to...... P.P.......
O.S. with............ V.= Jaeger............ to...... P.P.......
(V. Binocular............ added on............ Binocular P.P.......)

OPHTHALMOMETER SHOWS ASTIGMATISM } in O.D. of............ with axis + at............ or − at.........
in O.S. of............ with axis + at............ or − at.........

RETINOSCOPY INDICATES

O.D.

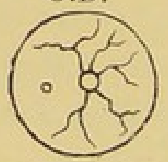


O.S.

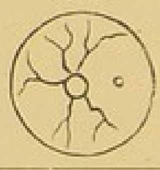
OPHTHALMOSCOPIC EXAMINATION SHOWS

FUNDUS

O.D.



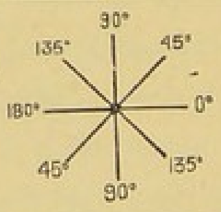
O.S.



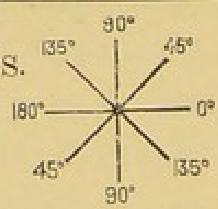
MUSCLE TESTS SHOW (*a*) *Esophoria* at............m. = ... at 25 cm. = ...
(*b*) *Exophoria* at............m. = ... at 25 cm. = ...
(*c*) *Hyperphoria* at.........m. = ...

RETINAL FIELD OF VISION

O.D.



O.S.



PRESBYOPIA.
Reads at. ....ins.
Amp. of Acc. ....
Lenses ....

LENSES PRESCRIBED. *Distance* { O.D.............V.=.............P.P. } Binocular
O.S. ....V.=.............P.P. } V.= ....
(Binocular addition = ...)

,, ,, *Reading* { O.D............. } Reads Jaeger No....................
O.S. .... } at................inches.

Here should follow details of frames.

REMARKS ....

CHARGES ....

APPOINTMENTS..

ALLOWANCES...

DATE AND METHOD OF DELIVERY...

Section V.

The Workshop.

Chapter XLIV.

THE NECESSARY TOOLS AND APPLIANCES.

IN dealing with the tools and appliances necessary for an optician's workshop it is proposed to describe such as will be most useful to one requiring to do necessary repairs at short notice, and to make such adjustments of frames and parts as are frequently needed.

A workshop must be equipped for utility. Some kind of work bench or board is indispensable, and this should be rigid, the top being free from seams into which filings or small screws might drop unobserved. If brazing and filing are contemplated then the front edge may be hollowed out and a jeweller's filing peg fixed in the centre of the hollow. A gas jet is inserted to the right hand, and a skin stretched underneath to prevent the waste of gold filings or other valuable small parts. Unless soldering and finishing of gold articles are intended the skin may be dispensed with, but the peg is very necessary. It is a piece of wedge shaped hard wood coming to a straight edge in front, the base being fixed into a slot in the front of the board. Filing can be done upon it with advantage, but not hammering. A vice also must be fixed, and it is well for this appliance to be placed near a leg or support, so that there may be freedom from jarring or shaking of the bench when it is used. This appliance may have 3 inch jaws, and if larger are necessary wooden cheeks may be added.

It is wise to banish all mercurial thermometers and barometers from a work bench, on account of the danger of mercury coming in contact with gold. This is ruinous to the surface of the metal, as it forms an amalgam, the removal of which destroys the appearance of the part so affected.

The gas-jet for use with a blow-pipe of any description should be horizontal, or the two may be combined in this position by using a small india-rubber tube attached to one of the arms of a T piece, the jet forming the other arm (Chap. LV). By means of a mouthpiece on the tubing the necessary blast can be obtained without having to support the rigid tube of the ordinary hand blow-pipe with the mouth.

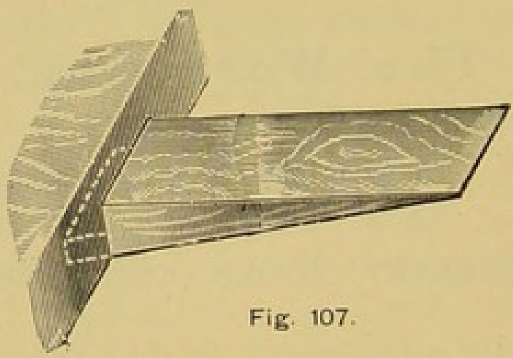


Fig. 107.

Jeweller's Filing Peg for Bench.

The work bench should be in a good light, either natural or artificial, and the grindstone must also be placed in a similar position, so that light may fall on the stone itself, and not on the back of the worker when grinding. If foot gear is used, it will be to the right of the stone, if a handle is fixed, it must be to the left.

A bench for optical testing and experiments may be placed at right angles to a window, and then a dark blind with apertures for the admission of small beams of light becomes very useful.

It is well to fix on the edge of the work bench a post of boxwood, or a strip of hard smooth wood with a clean, square cut face, against the upper part of which a spectacle joint may be held sideways, for the purpose of turning a screw. Several articles are now made to further facilitate this turning when screws are fixed in the joint through rust or corrosion. Amongst others a small tapered brass plate, with slots of varying widths, may be mentioned as useful, the joint being steadied by the sides of the slot, so that the screw can be more readily turned (Fig. 108).

Fig. 108.

Screw drivers are an absolute necessity, and the possession of several is an advantage, for, as the heads of screws are of different sizes, so the points of drivers should be varied. It is folly to attempt to remove a small gold screw with a wide pointed tool, which is certain to leave cuts and scratches on the surrounding portions of the joint. It is also unwise to take up a small pointed driver with the intention of turning a large headed screw. The edge of the screw driver point necessitates some consideration, for if it is not thin enough for the fine slots of small screws the joint is almost certain to suffer. Three sizes may be used with advantage, the points being $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 millimetres wide, the edge of the smallest being just visible as a flattened surface, while the other two may be thicker.

The handles of these tools should be large, as a good grip is necessary, and far fewer tool marks will be caused by turning the screw at the first attempt than by ineffective slips from the groove. A good grip is secured by several fingers and the palm of the hand giving a bearing on the tool, such as can never be got with the thin handled drivers used in watchwork. The blade should be long, of good steel, and well tempered. A wooden handle 3 or 4 inches long and 1 inch in thickness gives adequate power.

Pliers form a most essential part of an optician's outfit, and here, too, an advantage is lost by having the bows which are gripped by the hand too short, for considerable leverage is often required. They should be from 5 to 6 inches long, with the strongest jaws possible, consistent with the shape required, several different forms being necessary for perfect work.

Grindstones are an important item. Too often the error is made of buying a small stone intended for grinding edged tools. This is useless for good glazing, as it 'chips' the edges of all lenses, and sooner or later is bound to give dissatisfaction. The only stone really useful in so small a diameter as 1 foot is the Craigleith, used for smoothing edges of lenses. This is very hard, wears well, keeps an even surface, and lasts a long time.

Stones from 18 to 22 inches diameter and 4 inches thick are economical either for hand or foot power. They may be mounted in cast iron troughs to hold the water necessary for grinding, or may be purchased with spindle and bearings complete, and mounted in a wooden trough, which is better zinc lined than merely tarred. Splashing of the water caused by the revolving stone may be obviated by a zinc hood, fitting into the trough and allowing a good margin at the sides and top, where the water rushes round the grooves. For quick glazing by hand a wooden arrangement with sides sloping round the stone is probably better, as it enables a part of the edge not far from the vertical to be used, and the worker, being "over" the stone, obtains sharper cut edges on the lenses.

Grindstones may be divided into three classes, coarse, medium, and fine, according to the hardness of the stone. The coarser grained stones wear quickly, but cut more rapidly, while the finer grained ones are usually hard, wear longer and cut slowly, but leave the edges of lenses smoother. Bilston stones are coarse, quick cutters, very suitable for pebble lenses, and on account of the hardness of these a smoother edge is obtained than on glass.

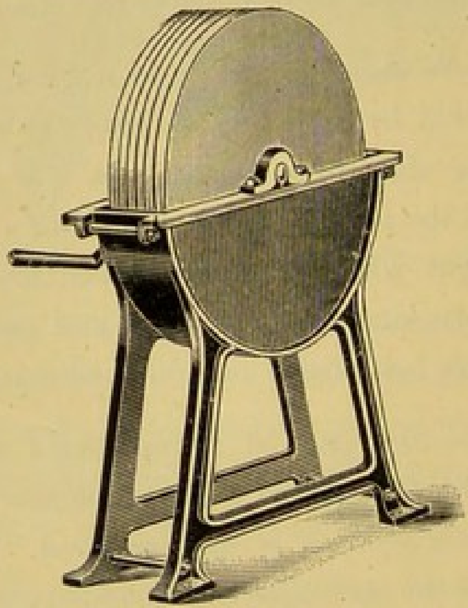


Fig. 109.

Grindstone grooved for use, on iron stand with trough and handle.

A good medium stone called "Adamant" is now produced artificially; being a slower cutter than the Bilston, it wears longer, and although it does not give so smooth an edge as a Craigleith, it is far better than the Bilston, and with due care very creditable work can be done upon it. Unless run by power the Craigleith is only useful for finishing or smoothing the edges of lenses, the fact of its being a slow and fine cutter prohibiting its use for general work, but as it wears for a long time only one groove is necessary, and thin stones will serve.

To keep stones in condition occasional truing is necessary, which reduces the size each time it is done. A stone with three or four grooves on its edge is proportionately much less trouble to correct, and wears longer than a narrower one with only one or two.

Glass nippers or shanks are for shaping lenses approximately to the size required for grinding. They consist of two pieces of iron about nine inches in length, loosely jointed at one end, with a pair of large scissor-like handles. Inserted into the inner sides, about two inches from their joint, are two soft iron cheeks, $2\frac{1}{2}$ to 3 inches long by $\frac{1}{2}$ inch wide, arranged so as to close parallel.

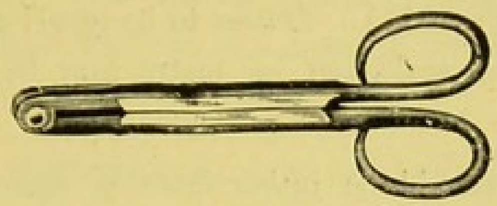


Fig 110.
Glazier's Iron Shanks or Nippers.

Lenses may also be cut to size by a diamond, the outer parts being broken away from the central portion outlined by the scratch on the surface, but for those who undertake varying sizes of work it is doubtful if much advantage is gained.

It is advisable to provide a series of standard eye-plates in metal, edged exactly as lenses would be, and also standard eyewires which exactly fit the plates. These are as necessary when frame proportion has to be considered as in glazing, for it is evident that when a lens is being edged it is far better to try it in a steel gauge than to unscrew a fine gold frame and constantly take the size from that, at the risk of bending or otherwise damaging it.

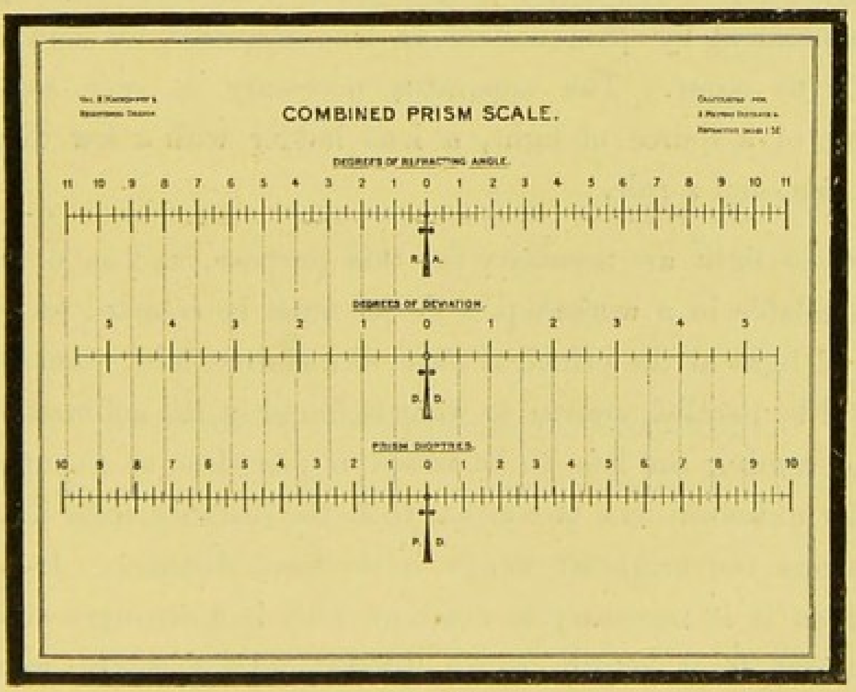


Fig. 111.

Various rules and scales are indispensable for measuring pupillary distances, and heights, projections and spreads of bridges of spectacles ; also some device for centering lenses correctly, and a protractor with degrees marked upon it, for the purpose of placing the axes of cylindrical lenses correctly.

A scale marked for estimating deviation in prism dioptres, degrees of deviation, and degrees of angle may be added with advantage, an excellent form being illustrated (Fig. 111). Lenses to be tested are held at a distance of two metres with this scale, but one metre may be used and the readings halved.

If files are used they should be rather fine cut, some flat, others with one surface "half-round." In the case of flat files it is well to have only two sides and one edge cut; the other (or "safe" edge), being perfectly smooth, will allow one of the sides to be used on a horizontal surface without the accidental filing of any vertical surface with which the edge may come in contact. Screw plates and taps are used for making the threads of screws, and for recutting screw holes.

Two items should not be overlooked, a leather or polishing cloth with a very small amount of rouge upon it, for brightening gold and nickelled steel before delivery to a client, and a small bottle of Rangoon or Vaseline Oil for the preservation of steel goods against rust.

It is always well for an optician to possess some means of measuring the focal length of spectacle lenses, independently of neutralization by test lenses and measurement by spherometers or lens-measures, for with these errors are liable to occur. The apparatus necessary is very simple, merely consisting of a source of light, a lens holder with a few diaphragms, a white screen, and a rule.

Parallel waves of light are necessary for this purpose, and as 6 metres is not always available in a workshop, a device must be resorted to by arranging a source of light at the principal focus of a convex lens, when the emergent waves will be parallel, similar to what is found in the collimator. The lens holder containing the lens to be tested is placed so as to intercept these, and if the unknown lens is convex, then the distance from it at which the screen shows the brightest image is its focal distance. If a concave is tested, then it is necessary to combine with it a stronger *known* convex, the resultant focal length, being divided into 1 metre, represents the difference in power between the known convex and the unknown concave. Thus, if a convex 5·00 D. is placed with a concave, which it exceeds in power, and an image is formed at 20 inches (50 cm.) away, evidently the concave must be $5{\cdot}00\ \text{D.} - \frac{100\ \text{cm.}}{50\ \text{cm.}} = 3{\cdot}00\ \text{D.}$ Weak convex sphericals may also be tested along with an added convex. Convex-plano cylinders give a line or streak of light, instead of the distinct image of convex sphericals, and convex sphero-cylinders give two streaks at different distances from the lens, the distance between being the *interval of Sturm* (Chap. XIX).

The source of light, the collimating lens and the lens to be tested should all be fixed parallel and truly centered, the base of the apparatus being scaled in inches and centimetres. It is scarcely necessary to add that a darkened room must be used.

Summary:—

(*a*) Use screwdrivers with large rather than small handles.

(*b*) The water in grindstone troughs should be kept as free from grit as possible.

(*c*) Mercury must be banished from a work bench.

(*d*) Good light is essential to successful work.

(*e*) An excess of tools is better than a deficiency.

Chapter XLV.

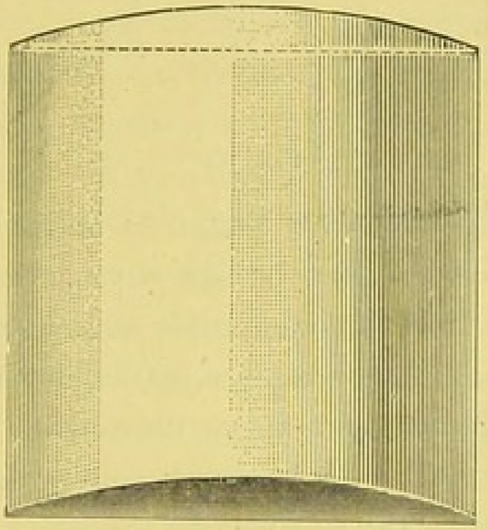
LENSES: CENTERING AND NEUTRALIZING.

BY the centering of lenses we refer to locating the direct optical centre, or the point where the principal axis of the lens would run through the lens. A lens may be cut which will not have an optical centre in the glass, but actually outside the periphery, so that, although in spectacle and other lenses the optical and geometrical centres usually coincide, this is not always the case. The geometrical centre is a point equidistant from the opposite edges, and is always constant, but the optical centre may be anywhere.

The method by which lenses are centered for optical use is to find the principal axis, upon which the optical centre lies, and in marking the latter upon the glass we really mark a point where the principal axis emerges from the lens. The actual thickness of lenses is not considered when thus marking their centres, but the relative thickness of one part of the same lens to another is of the greatest importance. In all lenses with a resultant positive power the centre will be on either of the two opposite points which correspond to the greatest thickness; but in all with a resultant negative power, upon those points which correspond to the thinnest portion, in other words, upon the opposite summits of the curvatures of any lens, so that we may centre a lens from either surface.

For plano cylinders this rule scarcely seems to apply; we find between A and B an infinite number of points which answer to the above description. It is evident that all these must lie in a perfectly straight line called the *axis of the cylinder*, which must not be confused with *meridian*,—an imaginary line passing across the centre of any curved surface. In any position at right angles to A B will be the greatest curvature; this is the *direction or meridian of greatest refraction*. Along the axis there is none, and we may, for clearness, speak of this as the meridian of no refraction. All conceivable lines drawn across this axis at the geometrical centre of the glass are also meridians, the curvature, and consequently the refraction, being different if the inclination to the axis is different, greater as they approach the position at right angles to it, and less as they approach the axis. Comparing a plano cylinder and a plano spherical lens of the same power, there is only one meridian of the cylinder which is precisely the same in curvature and refraction as every meridian of the spherical.

A



B

Fig 112.

If we place two plano cylinders of like kind and the same power together, with their axes at right angles to each other, it is evident that the two surfaces will present very different curvatures from the spherical which is equal in power to the meridian of greatest refraction of both of them; nevertheless, so arranged, their combined refraction through every possible meridian will be (for all ordinary purposes) precisely the same as in the spherical. The two axes form a cross, and the centre of that is the centre of the combined lenses. *This use of two plano cylinders of equal power and like refraction to give a spherical effect of the same power as the highest meridian of each of them is of the utmost importance to properly understand sphero-cylindrical equivalence.*

The great point in centering any spherical lens is to get it into such a position that the visual axis of one eye coincides with the principal axis of the lens in fixing a point at any distance. The simplest apparatus for the purpose is two cross lines, either ruled on a white card placed horizontally upon a table, or in the form of the cross bars of a window. The lens should be held steadily in the left hand some distance from and parallel to the cross, the eye being placed exactly above or opposite the centre, as the case may be, and a few inches away from the lens. No tilting of the lens or "cross" is permissible.

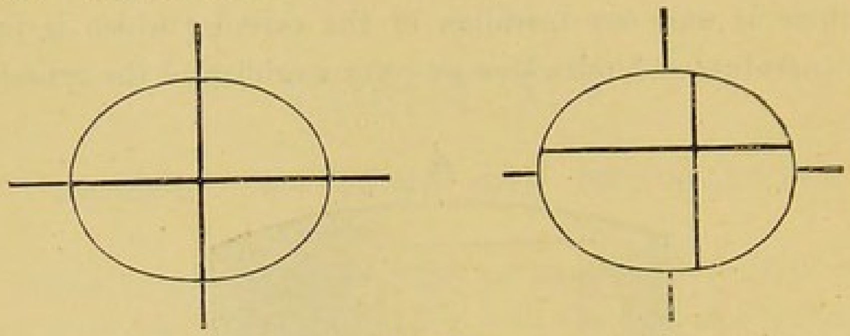


Fig. 113.

Viewing the cross through the lens a magnified image will be seen through a convex, and a diminished one through a concave. The object is to get alignment of the parts of the cross inside and outside the lens, as shown in the first illustration, any movement upwards, downwards, or to either side disturbing this. The second figure illustrates the appearance with an incorrectly centered lens. With strong convex lenses the movement of the image seen through the lens may be opposite to the motion of the lens or in the same direction, according as they are held before the eye at distances within or further away than their focal length.

It is of the utmost importance to properly centre lenses. Unless accurately done we do not put before the eyes of clients the glasses required to comfortably correct their defects. Fig. 114 shows two convex spherical lenses of equal power, and the section of the R. and L. eyes of a spectacle frame glazed with these two lenses, the L. eye correctly, the R. incorrectly.

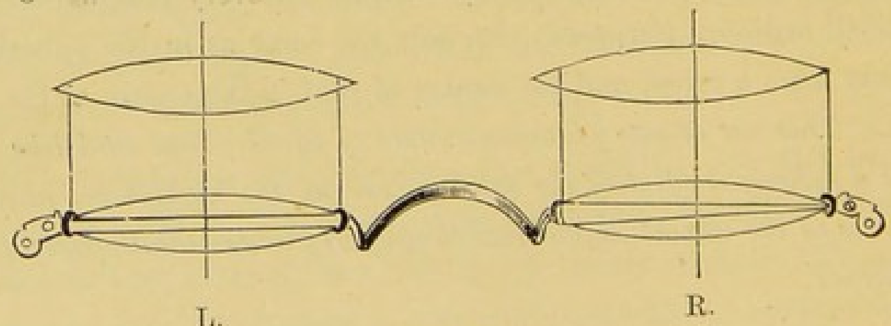


Fig. 114.

To make them fit into the eyewires lenses must be ground down at the edges to some little extent. We may, as in the illustration, draw two lines from the extreme edges of the curved surfaces, when, if the lens is properly centered, as in L. eye, there is simply the *equivalent* of a plane sheet of glass between them. But the R. eye shows a wedge of glass, in fact a prism with the base towards the nose, so that we should in this case be giving a sphero-prism where merely a spherical is intended.

Neutralizing a lens is really depriving it of all refraction, and this may be done by finding the opposite and equal power, which, when combined with it, will give the same effect as a sheet of glass with parallel surfaces.

In centering we noticed that the image seen through the glass moved with every alteration in position, and to annul this movement is the object in neutralization. The motion of the image is not the same for convex and concave sphericals, and it varies in extent with the power, being greater with the stronger lens. With a convex lens the image moves against the motion of the lens, a movement to the right displacing the image to the left, and vice versa, but with a concave the image moves with the lens, so that we can readily tell whether a lens is convex or concave. Combining a plus and minus lens tends to stop these opposite movements, and when the lines appear stationary on moving the lens in any direction neutralization is complete.

The neutralization of plano cylinders presents no special difficulty. We have already seen that there is a meridian of greatest refraction and one of absolutely none; for the former the movement will be at a maximum, and for the latter there will be none whatever. For any other meridian there will be a greater movement at the extremity than at any part nearer the axis. The consequence will be that in all positions of the cylinder except two, the lines will appear aslant.

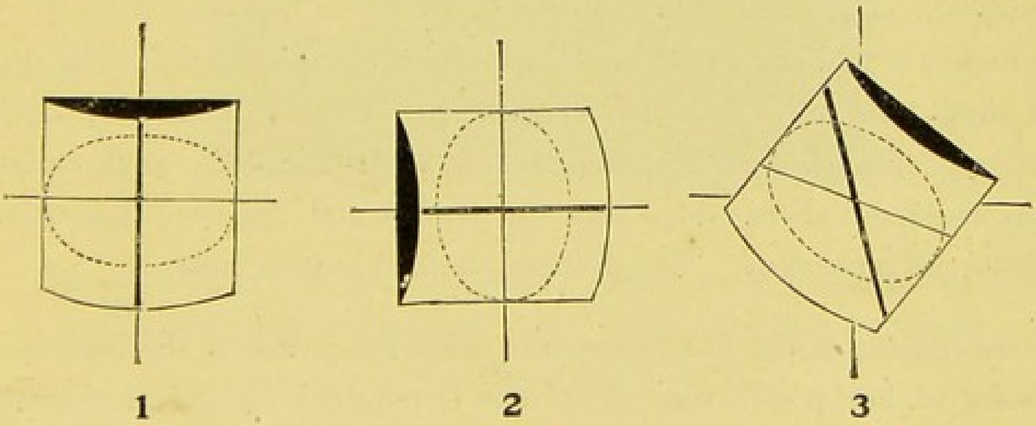


Fig. 115.

Nos. 1 and 2 illustrate the two positions referred to. No. 3 shows the lines aslant.

Finding the axis is the first step. The lens must be brought into such a position as to produce perfect alignment, as shown in Nos. 1 and 2 of Fig. 115. It is then moved up and down, and from side to side. For one of these directions there will be no motion of the image, but for the other there will be. *The direction of the movement which shows no motion of the cross lines is the direction of the axis of the plano cylinder.* Thus, in moving No. 1 *up and down*, the cross would appear fixed, and the axis is therefore vertical. The axis must be marked upon the glass with an ink or soap pencil line, and the corresponding plano cylinder of opposite sign found, which, when placed with its axis exactly upon the mark, stops movement in any direction. This determines the opposite equivalent power of the lens tested.

Sphero-cylinders, before neutralization, require careful centering and alignment, for it is evident that there will be a meridian of greatest refraction and one of least, at right angles to each other, and when these are exactly over the cross bars the images will be as in Fig. 115, 1 and 2. Before we can find precisely the axis of the cylinder the spherical portion must be neutralized. Trial with opposite power sphericals, in an up and down and side to side movement, will result in stopping movement in one direction of both the cross lines. Suppose this occurs for both lines during a side to side motion; the spherical is then neutralized, and at the same time we know that the cylindrical axis is horizontal. Having now to deal only with a plano cylinder, we find the opposite power which, when placed with its axis horizontal, neutralizes movement in the other direction. The spherical and cylinder combined are the opposite equivalent powers.

We may also adopt another method. Knowing that a sphero-cylinder has meridians of greatest and least curvature, it can be replaced by two plano-cylinders of unequal powers, with their axes at right angles. The opposites of these plano-cylinders will evidently stop movement of the image, when properly placed, and by methods to be explained in next chapter we can transpose them and obtain the powers and the two alternative axes of the unknown lens. The previous method is preferable.

As the movement of the image increases with the power of the lens, it is with lenses of low power that most care is required, for the movement being small, and their curvature not very apparent, it follows that neutralization is sometimes difficult to the novice. Moving one's self further away from the cross lines, and placing the lens much further from the eye, will make a movement more apparent. It must also be noted that if the lens is kept motionless, and the head moved up and down, or from side to side, the image moves with the head for convex, and against it for concave, quite contrary from what we found to occur during movements of the lens.

The case of deep lenses demands attention, for it is evident that deep convex lenses are much thicker in the centre than the concaves used against them. A deep convex, if it could be made infinitely thin, would practically neutralize a concave of the same power, the focal distance being measured from the optical centre. But as the focal distance of a thick double convex is *measured from the posterior principal point*, situated at one third the thickness inside, it cannot nearly coincide with that of the concave held against it, as is necessary to make the posterior foci coincide, and so obtain complete neutralization. This applies throughout, but the difference is so small in lenses of medium and low powers as to be negligible. Not so in lenses of appreciable thickness. Plus 9·00 D. combined with minus 9·00 D. results in a difference of about plus 0·25 D., while with 20 D. lenses it amounts to over plus 1·00 D., plus 19 D. practically neutralizing minus 20 D.

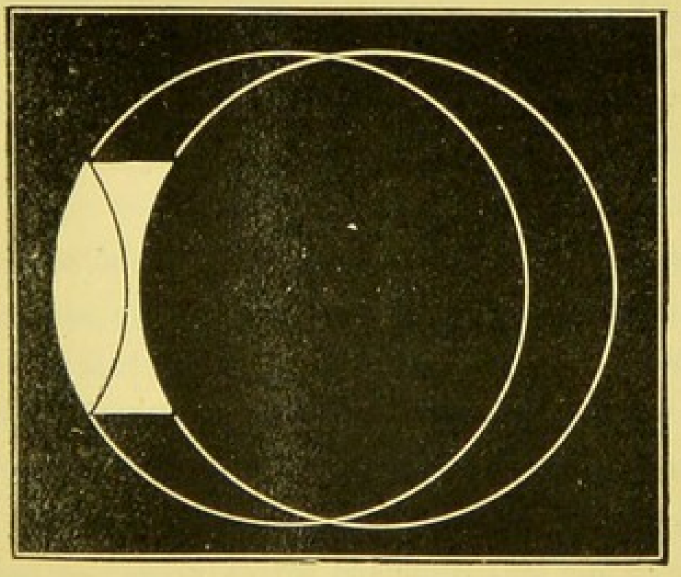


Fig. 116.

The circles show that the curvatures are the same, but it is evident that the combined plus and minus lenses form a portion of a crescent which is a periscopic convex lens.

The result is, that using a series of pairs of strong lenses, we have to choose between powers plus and minus which will neutralize, *or lenses of opposite equal curvatures which will not neutralize.* The demand for lenses which shall neutralize has caused manufacturers to lessen the curvatures of all deep convex lenses from about 8·00 D. upwards, so that the numbers which these have marked upon them are not true indications of their refractive power. The difference of power between deep lenses of opposite character (contrageneric) but of the same curvature, may be graphically illustrated (Fig. 116).

The neutralization of periscopic convex lenses presents a similar difficulty, for there is not coincidence of the surfaces when a concave neutralizer is used. At whichever side of the lens it is placed, an intervening small lens of air is formed, convex in the one case, concave in the other. For this reason neutralization does not seem so complete with the lenses in one position as in the other. A trifling discrepancy occurs with pebble lenses of high power, for the curvatures of the surfaces are less than with glass for the same power.

Some interesting features of neutralization are observed by using a square with prolonged sides as shown in Fig. 117.

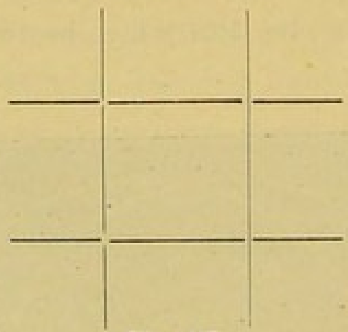


Fig. 117.

In plano cylinders and sphero cylinders with powers of same sign (congeneric) this may be used to find the axis directly, for the square in all such cases appears through the lens as an oblong when the lens is adjusted for the lines of the image to be vertical and horizontal. In convex lenses the axis will be *across the direction of greatest length*, and *across the direction of shortest measurement* in concaves.

The neutralization of any lens combined with a prism can be effected by means of the cross lines. With a plano prism before the eye, and parallel to the plane of the cross lines, we see merely a permanent displacement of the whole cross towards the thin end or apex of the prism, and no such motion of the glass alters this, as it did in the previous cases.

A certain base-apex line, extending from base to apex of the prism, should be marked, and this must be made continuous with one of the viewed lines, both inside and outside the glass, and however we may combine a prism with other lenses, it always has the apparent effect of displacing the object viewed along this line from base to apex.

A sphero prism will displace the bars, and the new position of the centre of the cross must be observed, and the direction of its displacement noted. If cross lines be now marked upon the lens, so that their centre is at the geometrical centre of the lens, the image can be made to coincide with these by means of a prism placed with its base apex line along the line of displacement, its base being towards the direction of displacement.

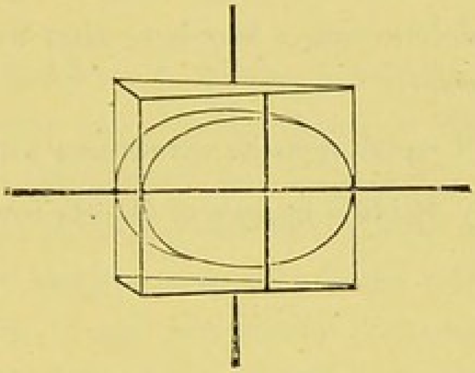


Fig. 118.
Prism held over cross lines, showing the outline of an oval lens cut from it.

To neutralize a sphero cylindrical prism the cross lines must be made continuous, and while the lens is in this position the spherical and cylindrical elements can be neutralized. Then the *optical centre* of these glasses must be placed over the geometrical centre of the lens tested, when any deviation of the cross lines will be due to the prismatic element only, and this can be neutralized as described for a simple prism.

The effect of decentration of a lens may be calculated in prism dioptres and degrees by two simple rules :—(*a*) For every centimetre of decentration in a lens as many prism dioptres are produced as the lens has dioptres of refraction. Thus a + 3 D. decentered 2 centimetres will give 6 prism dioptres. (*b*) A decentration of $\frac{1}{100}$th inch for every inch of focal length of the lens gives 1° prism ; so that for 2° in a 10 inch lens we shall have to decenter $\frac{1}{5}$th inch (about 5 mm). This rule is merely approximate, but very close.

Summary :—

(*a*) Lenses may be centered from either side, at the points where the principal axis emerges from the glass.

(*b*) A plano cylinder has a meridian of greatest curvature and a line of no curvature, called its axis.

(*c*) Two like cylinders of the same power with their axes at right angles are equal to a spherical of like kind and the same power as one of them.

(*d*) Images seen through a plus lens move against the motion of the glass, but through a minus lens with the glass, provided the eye does not move.

(*e*) The effect of decentering a lens is to alter its character by introducing prismatic power.

(*f*) Deep lenses of equal opposite curvatures will not neutralize.

(*g*) Prisms merely displace images of objects towards their apices.

Chapter XLVI.

CYLINDERS: SETTING AND TRANSPOSING.

THE fact that any cylindrical or sphero-cylindrical lens has a meridian of greatest refraction and one of least, makes it clear that care is required when placing any of these lenses before the eye to correct a defect. The axis of the cylindrical portion of a lens is always used as a guide in fitting the glass to a frame, and the most convenient way to indicate its position in the lens in relation to any given point is to use a protractor or circle divided by radial lines into sectors of 10° each, with an intermediate mark for 5° divisions. This enables the lens to be placed exactly in the position required, when the angle is specified, so long as we know the situation of 0° or zero.

The notation or reading in most general use amongst opticians, known as the *Standard Notation*, is one which will apply equally to both eyes, and has the zero at the R. side of the horizontal diameter, so that 90° is vertical and 180° is the L. side of the horizontal. This represents the position when we are looking at the front of a spectacle, and consequently into the wearer's eyes. The sectors in the lower half must be numbered the same as those in the upper, therefore the vertical line is marked 90° at both ends, but the zero or 0° must face 180°, (the latter number always being used in prescriptions), otherwise there would be confusion. By this arrangement the lower half is an extension of the upper, and also represents the scale engraved on the rims of the trial frame.

There are many other ways of numbering the meridians. Many oculists and medical men still use a method which is different for the two eyes, the zero being in both cases on the temporal, and 180° on the nasal sides (temporal zero). Others place these degrees exactly the reverse (nasal zero); while a third method starts with zero at the top (vertical zero), and works down to 90° at both nasal and temporal sides. In only one of these methods will the mere figures, without some indication of the position referred to, convey exact information which will enable a cyl. axis to be placed correctly for either eye.

To find the angle at which the axis of an unknown edged or shaped lens is *set*, we must first ascertain its exact position on the lens by methods already described, an ink mark or thin strip of gummed paper locating it. The lens is laid on the protractor in a perfectly horizontal position, so that the line which represents the long axis (if oval or pantoscopic) shall run exactly over the central line of the protractor. The geometrical centre of the lens must coincide with the centre of the protractor, and the mark indicating the axis will then point to the required degree on the circumference. It is necessary, before deciding this, to know which side of the lens is used next the eye. In many cyl. and sphero-cyl. lenses there is only one correct position in which the lens may be screwed into the frame. There are various considerations which affect this in the original glazing, but it is certain that in every case the portion of the lens of least curvature, if convex, or of greatest curvature, if concave, should come next the eye. Cylinders with axes vertical or horizontal may be reversed from back to front without changing the position of the axis, but for cyls. with axes in any other position it is absolutely necessary that they are always placed with the same surface inwards, even if the curvatures are similar, for a reversal of the lens will mean a change in the axis. Thus, if a cyl. is glazed to a frame with the axis at 135°, and it is screwed in back to front, the lens will have its axis at 45°. Changing such a lens, so that the nasal end is placed at the temporal, keeping the same side next the eye, will not alter the axis. But should a prism enter into the combination, there is one position only which will be correct, for the lens cannot be reversed, or turned upside down, without completely altering its effect.

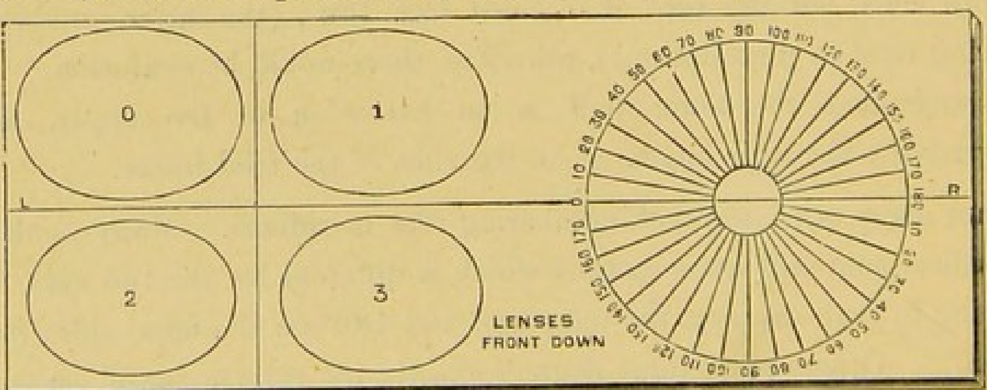


Fig. 119.

Centering scale with reversed protractor and standard sizes.

Should the lens be in a frame, it is evident that the sides of a spectacle, or the plaquets of a folder or clip, will prevent it being brought near the protractor, and so be a source of possible error. For this reason reversed scales are printed on a protractor, so that the front of the frame (the surface furthest from the face) may be laid on the scale, the sides standing away. By this arrangement lenses need not be taken from a frame to be tested, before being handed to a client, thus obviating possible errors in replacing them.

To transpose a lens is to change the curvatures of its surfaces without altering its power, and we cannot do this without altering the curvatures of both sides. The changes from plano convex to a double convex or periscopic lens of the same power are transpositions of sphericals, but our present concern is with the transposition of lenses in the refraction of which there is a cylindrical element, and the necessity for transposition depends to a great extent upon the peculiarities of each case, as explained in Chap. XL.

The best way of learning to transpose is to use a small diagram of the cross lines at right angles to each other, and work cases out graphically until the method is thoroughly mastered. No series of rules is then necessary, but there are two points which must always be borne in mind:—(a) *A spherical lens is equivalent to two like cyls., each of the same power as the spherical itself, placed with their axes at right angles to each other.* (b) *Whatever power is added to one surface of a lens demands an equivalent subtraction from the other to keep the lens of the same refraction.*

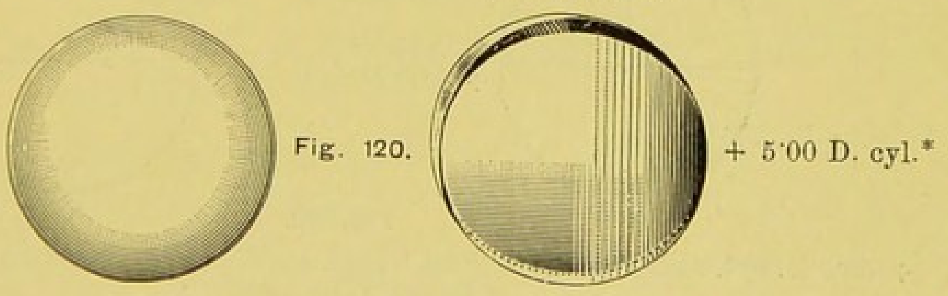


Fig. 120.

Graphical illustration that:—
+ 5·00 D. sph. = + 5·00 D. cyl. axis vert., ◯ + 5·00 D. cyl. axis horiz.

Fig. 120 shows lenses of equal powers but different forms, the second combined lens showing a plus 5·00 D. cyl. axis vertical on the front, with a plus 5·00 D. cyl. axis horizontal on the back surface. This is based on rule (a) above.

* To show the edges of the lenses the combination is tilted so that the axis, as indicated by the thick edge on the left, does not appear horizontal.

Fig. 121 illustrates (b). In the first diagram if we *add* + 5·00 D. cyl. axis vertical, to the front surface, converting it into a spherical, to compensate we must take away + 5·00 D. cyl. axis vertical, from the back surface. The power is not disturbed, but we get the lens as shown in the second illustration. *To take away a plus lens is the same as adding a minus lens*;

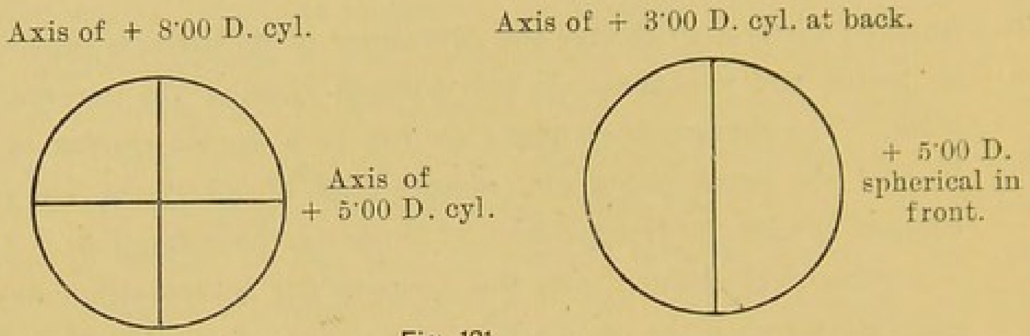


Fig. 121.

+ 8·00 D. cyl. axis vert., ○ + 5·00 D. cyl. axis horiz., = + 5·00 D. sph. ○ + 3·00 D. cyl. axis vert.

so that we have really placed an additional + 5·00 D. cyl. on the front, and a − 5·00 D. cyl. on the back, at the same axis. As these are the same power, but opposite signs, it is clear that we have not altered the refraction of the original lens.

We might have done this in another way, as shown in Fig. 122.

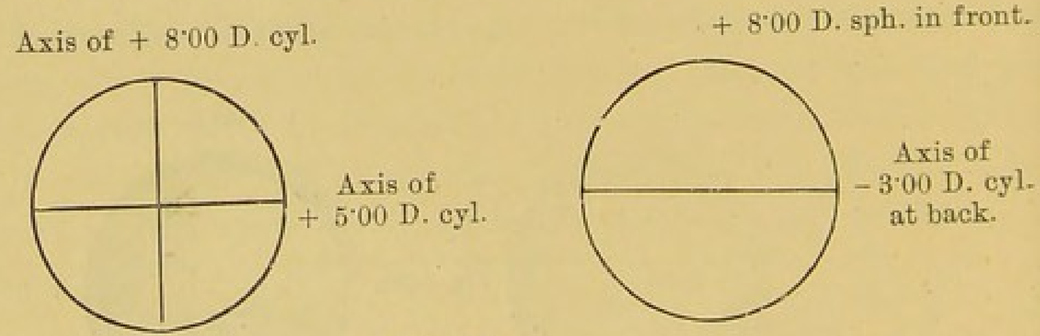


Fig. 122.

+ 8·00 D. cyl. axis vert. ○ + 5·00 D. cyl. axis horiz. = + 8·00 D. sph. ○ − 3·00 D. cyl. axis horiz.

In this case we have added + 8·00 D. cyl. axis hor. to the front surface, converting it into a spherical, and added a − 8·00 D. cyl. axis hor. to the back surface (adding a minus is equivalent to subtracting a plus lens) without altering the refraction. Complete mastery of these simple processes of addition and subtraction of lenses is the secret of successful transposition.

We pass to the consideration of the two sphero-cyls. obtained, the one + 5·00 D. sph. ○ + 3·00 D. cyl. axis vert. convex on both surfaces, the other + 8·00 D. sph. ⌢⌣ − 3·00 D. cyl. axis. hor., convex on one surface and concave on the other. The latter form is equal to $\left\{\begin{matrix}+\ 5{\cdot}00\ \text{D. sph.}\\ +\ 3{\cdot}00\ \text{D. sph.}\end{matrix}\right\}$ ⌢⌣ − 3·00 D. cyl. axis hor. Again we may write this, + 5·00 D. sph. ⌢⌣ + $\left\{\begin{matrix}3{\cdot}00\ \text{D. cyl. axis hor.}\\ 3{\cdot}00\ \text{D. cyl. axis vert.}\end{matrix}\right\}$ ⌢⌣ − 3·00 D. cyl. axis hor., by dividing the + 3·00 D. sph. into two + 3·00 D. cyls. with axes at right angles. But it is evident that the + 3·00 D. cyl. axis hor. and − 3·00 D. cyl. axis hor. neutralize each other, so that the remainder is + 5·00 D. sph. ⌢⌣ + 3·00 D. cyl. axis vert., the equivalent form of Fig. 121.

We may, from the above working, formulate a rule for guidance in transposing sphero-cyls. from one form to another :—*The new spherical will be equal to the algebraic sum of the original sph. and cyl. elements, and the new cyl. will be the same power as the original cyl., but with opposite sign, and axis at right angles.*

A few examples will illustrate :—

(1) + 3·00 D. sph. ⌢⌣ + 2·00 D. cyl. axis vert. = + 5·00 D. sph. ⌢⌣ − 2·00 D. cyl. axis horiz.

(2) − 3·00 D. sph. ⌢⌣ + 4·00 D. cyl. axis 80° = + 1·00 D. sph. ⌢⌣ − 4·00 D. cyl. axis 170°.

(3) + 2·00 D. sph. ⌢⌣ − 3·00 D. cyl. axis 10° = − 1·00 D. sph. ⌢⌣ + 3·00 D. cyl axis 100°.

(4) − 4·00 D. sph. ⌢⌣ + 4·00 D. cyl. axis 45° = − 4·00 D. cyl. axis 135°.

The first needs no explanation, but in (2), to get the new spherical, − 3·00 D. added to + 4·00 D. gives + 1·00 D. This is precisely what we should obtain by placing a 3·00 D. concave and a 4·00 D. convex together. The same thing occurs in (3), but in (4), as the figures are equal and opposite, evidently there will be no spherical effect, and the transposed lens is a plano cyl.

The form of a toroidal curvature has been explained in Chap. XIX, and toric lenses may be centered and set exactly as sphero-cyls., from which they differ inasmuch as the one surface is toroidal instead of cylindrical. This surface is ground on what is known as a *base curve*, usually about − 6 D., so that with the one axis − 7 D. we should have a surface showing a difference of 1 D. in the two meridians. The opposite side is used for grinding the spherical necessary to get the sphero-cyl. required. Thus, suppose a lens + 2 D. Sph. ◯ + 1 D. Cyl. is asked for. The equivalent toric would be + 9 D. Sph. (on one surface) ◯ toroid − 7 and − 6 (on the other surface).

We have so far assumed that transposed lenses, of whatever form, are exactly equivalent in power to the original, and for the purposes of correction of ocular refraction this may generally be taken as sufficiently accurate, but reference to the Gauss system (Chap. XX.) will at once show that the principal planes will not occupy exactly the same positions, being displaced according to the shape of the lens. As the focal length is measured from these planes (which are in this case coincident with the nodal planes), it is evident that, in front of the eye they are not quite the same, and there are some persons who will detect the difference. For the same reason, when they are neutralized, the lenses of opposite power should be held so that their p.ps., are as nearly as possible coincident with the estimated p.ps., of the lens of deep curve.

Summary:—

(*a*) The *Standard Notation* is the only one which will indicate exactly the position of any axis for either eye without further description.

(*b*) The greater curvature if concave, the lesser if convex, should come next the eye.

(*c*) Lenses should not be reversed in any direction, even in the same eyewire.

(*d*) The essential points for transposition are :—

(*a*) A sph. lens = two crossed cyls. each of its own kind and power, with axes at right angles.

(*b*) Whatever is added to a lens must also be subtracted, to retain the same power.

(*e*) In transposition of sphero cyls. the new sph. equals *in power* the algebraic sum of the sph. and cyl. elements of the old, and the new cyl. is same in power as the old cyl. but with opposite sign and axis at right angles.

(*f*) For contrageneric crossed cyls. *either* cyl. may be written as a sph., the sum of the two powers with the sign and axis of the *other* cyl. giving the new cyl.

Chapter XLVII.

TYPES OF FRAMES AND THEIR USES.

THE various types of frames may be considered from two stand-points :— The purpose for which they are intended, and their cosmetic effect. As it is sometimes necessary to meet the wishes of a client, the second assumes an undue importance, but usually a compromise is possible, always giving due consideration to the first. Many frames can be made in three forms, so far as the arrangement for holding the lenses is concerned, the most usual being that in which the V edge of the lens sinks into an eyewire and is clamped by it, but the eyewire may be made perfectly round, and sunk into a groove cut out from the flat edge of a lens, being then known as "invisible." A third method is to flatten the edge of the lens and attach it to the necessary "holders" by small screws inserted through holes drilled in the glass, when the article is known as "rimless" or "frameless."

The second and third types are used purely for cosmetic effects, and while appearing very light are rarely so actually, for the edges must be much thicker than the fine V shape of the first, giving a greater weight to the lens. The grooved concaves are an exception in this respect, as the edge of these always has more or less thickness. Any advantage gained by grooving is counterbalanced by increased liability to breakage and unsightly chipping of the glass.

Certain forms of pince-nez, which have a good grip on the nose, do not fold up, and need no handle or catch, have a very light appearance as rimless ware, and for myopes are sometimes very convenient, especially where the myopia, as is not unusual, is accompanied by a good nasal development. With medium and high power convex glasses their utility is considerably lessened, for their edges must have a considerable thickness to provide against frequent breakage at the screws. Consequently the lenses become unduly heavy, and necessitate a strong grip on the nose by the spring to prevent their falling off.

Spectacle frames are the principal form of holder in which lenses are mounted, but the various devices coming under the general term "clips" have grown in favour of late years. In both these cases the primary usefulness is due to the lenses being maintained in the same position before the eyes every time the wearer places them on the face. Here spectacles are better than any other device, for although by use the wearer may succeed in adjusting the plaquets of a clip at the same height on the nose, and approximately the same distance from the eye, there are not always safeguards against the lenses tilting forward and producing cylindrical effects. It is absolutely essential that any lens having a cylindrical or prismatic element shall be held as correctly as possible before the eye, so as to secure perfect coincidence of the axis of the cyl. with the necessary meridian of the cornea, or of the base of the prism with its required position.

Spectacles are made in many forms, each having certain general or particular advantages for the purpose intended, the straight side combined with the crank bridge being the one most frequently found in ready made stock. Probably of all forms this is the one most easily fitted by the optician, and adjusted on the face by the wearer, consequently for presbyopia, where the client often merely seeks to obtain a correction for near work, it is very useful.

For constant wear some form of spectacle is generally used which relies upon a bend in the sides to keep it in position. The old arrangement of a jointed side, in which a short end piece turned down, giving it the name of "turnpin," has almost disappeared from modern frames, and the excellent "bent" side, which is merely a stiff straight side with a slight curve about one or two inches from the end to go behind the ear is not in very general use, having been replaced by the true "curl," "hook" or "riding bow" side. This is of much the same shape, but of round thin wire, gripping the ear, whereas the bent side merely acts as a sort of stop, preventing the front of the spectacle sliding down. The "cable" or twisted wire of the same form as the curl is now much used. The advantages of each of these will be considered in Chap. LI., but any now in vogue may be satisfactorily combined with the W bridge.

Some oculists prescribe round eyes for all purposes, maintaining that a large circular lens allows freer play of the eyes without the rims of the frame coming into view, but this provision seems superfluous when we consider that the upward range of movement of the eyes (sursumvergence) is but small in amount compared with the lateral movement. Round lenses have an advantage in allowing the axis of a cylindrical lens to be adjusted by rotation of the glass.

For reading and close work some form of spectacle with straight sides is an advantage, as any sides which grip round the ear are troublesome to a wearer who has to remove his spectacles whenever objects at a distance claim attention. The bridge takes various forms, the crank, arch and W all being shapes in general use for near work. The most suitable form of lens should be decided by the requirements for each individual case, a shape known as "pantoscopic" (meaning literally "to see all"), being preferred by some. The lower half of the lens is of the usual oval shape, but the upper half is made with a top more or less flattened, even being ground quite flat in what is called the "clerical" form, which allows the visual line to be directed above the eyewire, so that the lens is only used for near work. The pantoscopic frame is often better adapted for reading by having the front tilted forward a little, (by "angling" the joints), and this in combination with periscopic lenses is a useful adjustment, by means of which light incident upon the glass from close work is almost normal to the surface.

The pantoscopic shape is not always confined to this use; there are many persons who have prominent eyebrows, the frontal bone protruding over the eyes, so that the eyeballs seem sunken, and here oval lenses would have to be both long and narrow to fit under the eyebrows, or else placed at such a distance from the eye as could not be in the best interests of vision. By slightly flattening the top of any usual oval shape a "deep" pantoscopic eye is formed which overcomes this difficulty.

A further variation of the type is the "reversed panto" (sometimes called "half eyes"), having a perfectly flattened *lower edge* for the convenience of myopes who require concave glasses for distance only, reading being comfortable to the unaided eye. This form of frame is rarely called for, the advantages being chiefly noticeable by public speakers and artists. In neither of the last two variations would the joints be angled.

There are occasional cases where one eye only can be used, and different lenses are required for distance and reading. Several types of straight side frames are made to suit such, the W, X, and K being the bridges fitted for this particular purpose. By making the W bridge on the central line between the joints, with the whole plane of the bridge at right angles to the front, the spectacle may be worn with either lens before the seeing eye. So also may the X and K bridges be used, but with the last mentioned it is noticeable that in one position of the frame the lenses will fall lower on the face than in the other, thus providing an adjustment for distance and reading. With the X and K bridges the sides may also be "curl" or "cable" and be reversible, turning freely from one side of the frame to the other.

In reversible frames for large and high noses the arch bridge must be used, by means of which the greatest amount of space can be secured, and it may be placed as high as necessary. Round wire must be employed in making it, otherwise there will be a sharp cutting edge in some position of the flattened crest.

The word "clip" covers a multitude of patterns, which may be grouped under three forms :—(a) Those depending for their grip of the nose upon sliding bars, and closing, after being pulled open horizontally, by the recoil of a spiral spring. (b) Those with a rigid fixed bar, with spring plaquets on the eyewire for nasal grip. (c) A varied class with more or less elastic tempered springs connecting the two eyes, obtaining their holding powers by the tension of some portion of this spring.

The first class is much used at the present day, and the lenses being kept perfectly horizontal, when the frame is properly placed on the nose, secures a constant position for the axes of cylinders. They are made with one, two or three round bars, the single bar being divided longitudinally by a vertical or horizontal section. These, with wear, "rock" or twist from front to back, looking very awkward when upon the face, and also displacing the true plane of the lenses. Some of the double bars are also liable to this, and although the treble form is more rigid, it is apt to get out of order by loss of parallelism of the bars and careless manufacture, the ends of the moving parts being frequently loosely soft soldered into the sockets.

A square bar, similarly divided, is also made, but probably what are known as flat or oval bars are the best forms for hard wear. They are similar in shape, longitudinally divided, with a coil of spring wound round, and by the form of the sliding portions it is evident that they will not "rock" so readily as the round bar, the thin edge presented to any one viewing them on the face giving a very neat appearance, especially in the case of the oval bar.

The disadvantages of the second group lie in the more or less fragile character of the springs which give the necessary contact grip to the plaquets. Being attached to these they are always liable to injury, and consequently cause annoyance to the wearer. Otherwise they are commendable, especially as many patterns can be put on with one hand.

In class (c) the fact of having a spring, upon the tension of which depends the grip upon the nose, lessens their value with cylindrical or prismatic lenses, for it is necessary to use every precaution that these are held before the eyes in a constant position. Some, made in rimless form, are very convenient, and pleasing in appearance, and for cosmetic effect are difficult to replace by other shapes.

The eyeglasses known as "folders" depend for their hold upon a curved, tempered, flattened thin piece of metal, technically known as the "spring." Attached to the eyewire in various ways are broad pieces of cork, tortoise-shell, xylonite, rubber or horn, which form pads, protecting the nose from being marked by undue pressure. Various devices further ensure this, but they are all on similar principles, and however arranged are merely useful for spherical lenses. Their great disadvantage is their unreliability for maintaining a constant position of the lenses in front of the eyes. As frequently seen, the long axis of the lens is far from horizontal, and the centres of the lenses are often incorrectly placed before the visual line.

For clients who persist in wearing these articles for reading purposes the pear shaped form may be suggested. This avoids the frequent annoyance and confusion caused by the inner and lower portion of the ordinary oval eye-wires appearing in the field of sight when looking downwards, the adhesion of plaquets to rims facilitating a clear and uninterrupted view, but *very careful adjustment of the optical centres is necessary.*

Grab fronts are made, consisting of two eyes joined by a rigid bridge, with bent wires on the ends of the eyes for fitting to the joints of a spectacle while on the face. They are used to provide the additional power requisite for reading in presbyopic cases. Some grab fronts are made with a spiral spring (like clips) and are thus almost self centering on any spectacle.

Summary :—

(*a*) Invisible and rimless fittings rarely ensure extra lightness.

(*b*) Spectacles are unsurpassable for cylindrical and prismatic corrections, and for comfort.

(*c*) Periscopic lenses in an "angled joint" pantoscopic frame form a useful combination for reading spectacles.

(*d*) Folders should not be given with cylindrical lenses or prisms.

CHAPTER XLVIII.

FRAME PROPORTION AND MEASUREMENT.

FRAME proportion and measurement must be carefully studied in connection with Chap. XLII., for it is quite possible to make a spectacle, folder, or clip frame to fit a face so far as pupillary distance, height of bridge, &c., are concerned without giving the necessary proportion between *all* parts. There are thus various points in frame manufacture which should be understood before fitting is attempted, as it is not unusual for the beginner to give either a series of measurements which cannot possibly be complied with, or details which, if followed, would result in a frame quite disproportionate and ugly.

The size of each part in an ideal frame should be proportionate to other parts, chief in this respect being the relation of eye sizes to centres of spectacles. Some amount of latitude is occasionally necessary, but to exceed certain limits is unwise.

The Optical Society has standardized many details connected with optical frames, and these are given at the end of the book. The sizes of eye are identical with those used in America, but the numbers denoting these sizes are different. As by far the majority of opticians still used the American numbers, they are employed here, and the O.S. numbers corresponding to them are only used in the details referred to above.

The measurement of the "centres" of a frame, or the distance exactly corresponding to the P.D., may be made in millimetres or inches, and it will be found that for given centres certain sizes of the "eyes" will form the best proportioned frame for all the usual types of features.

These may be tabulated as follows, using the American sizes, centres being expressed in inches and nearest mm. equivalents :—

Centres of Frames.	Size of Lens.
51 mm. (2 inches)	No. 3 eye (35 × 26 mm.)
54 ,, ($2\frac{1}{8}$,,)	,, ,,
57 ,, ($2\frac{1}{4}$,,)	No. 2 eye (36 × 25 mm.)
60 ,, ($2\frac{3}{8}$,,)	No. 1 eye (37 × 28 mm.)
63 ,, ($2\frac{1}{2}$,,)	No. 0 eye (39 × 30 mm.)

No size less than 35 × 26 mm. is advisable, even for the small pupillary distances of children, and roughly speaking, a difference in the centres of 3 mm. justifies the substitution of a lens one size larger, which will mean an increase in the length of each lens of 1 mm. in all sizes except No. 0 eye.

Attention must be given to the space available between the eyewires for the bridges of spectacles. This will be equal to the measurement of the centres less the length of one eye of the frame, which includes the long diameter of the lens and an allowance of 1 mm. for the eyewire.

For centres of	51 mm.	with No. 3 eye	the available space is	15 mm.
	54 mm.	,,	,,	18 mm.
	57 mm.	No. 2 eye	,,	20 mm.
	60 mm.	No. 1 eye	,,	22 mm.
	63 mm.	No. 0 eye	,,	23 mm.

It is evident that the greatest care must be exercised in the choice of a suitable bridge for any of the smaller centres, as there is less space available, whereas the *nose* which it is required to fit may be as broad as one which is combined with a much wider pupillary distance. Using the same size of eye and reducing the centres will diminish the nose space, but increase of this space will increase the centres. Using the same nose space, a larger eye gives wider centres, whereas a smaller eye gives narrower centres.

In addition to the centres the frontal measurement of a spectacle claims attention. This includes the joints up to the pins, so that if a joint is increased in length it will cause a difference in the measurement from end to end of *twice* the amount it has been lengthened. The average length of these pieces is about 6 mm., therefore the usual frontal measurement is from 46 mm. to 48 mm. more than the centres.

In writing out details for a special frame not infrequently an impossible combination is formed of centres, size of eyes, and front. Such might occur when a large lens is required for a client with wide P.D. and sunken temples. Presuming that the centres are 63 mm. and No. 0 eye (Amer.) is *necessary*, then adding 1 mm. for eyewire, it follows that without the joints the frame measures 103 mm., and as the shortest form of joint will be about 3 mm., the smallest front which can be made for this spectacle will be 109 mm., unless a *smaller* eye is used. A disproportionate frame often results from the desire of a client with very wide P.D. and full temples for a small eye. For example: A frame is proposed necessitating 66 mm. for centres, and a No. 2 eye is specified, resulting in a space of 29 mm. for the bridge, whereas 23 or 24 mm. would be ample. Pantoscopic eyes may be measured similarly to oval ones, the lower *halves* generally taking somewhat the same oval form, while the upper halves are flattened. Specifying the length and breadth will ensure similar proportions to what are found in the corresponding oval forms.

To measure the centres of a spectacle frame it is merely requisite to take the distance from the end of one eyewire near the nose to the end of the other near the joint, equivalent to measuring from the centre of one lens to that of the other, and much more exact. In calculating the size of a spectacle eye, 1 mm. must, on the average, be added to the size of the lens which fits it, both in length and breadth, to allow for the eyewire, except in invisible and rimless spectacles.

Measurements of the bridge demand special attention, no less than six factors entering into a complete specification. These are (a) Height above the centre line of the joints. (b) Projection or recession from the vertical plane of the lenses. (c) Width of the base, inside the widest part. (d) Shape of the crest. (e) Depth of bridge. (f) Angle of the crest. These will be considered in detail in a separate chapter.

Several scales have been devised for measuring the various parts of a spectacle frame, a simple form of such being shown in Fig. 123.

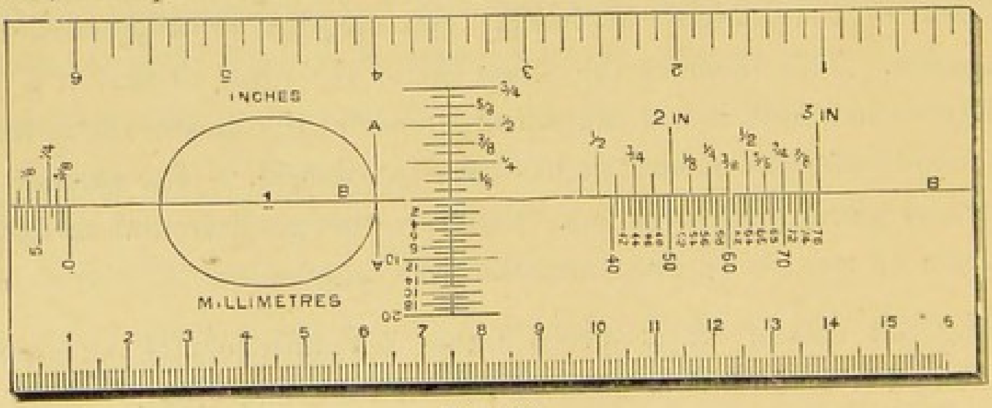


Fig. 123.

The horizontal line B.B. indicates that which passes through the centre of both joints when the frame is laid front down upon it. Another small vertical line A.A. provides a fixed position for the nasal end of one eyewire, the temporal end of its fellow indicating, towards B., the centres both in mm. and sixteenths of an inch.

Two small vertical scales show the height of any bridge, while the spectacle is in the correct position, one being in mm., and the other in sixteenths of an inch, and a further similarly divided scale at the end is useful for measuring the projection or recession of bridges.

It is well to observe that a heavy gold eyewire will give the contained lens a smaller visible size than a light steel one, the deeper groove allowing the glass to sink further in, with less of the lens visible. In measuring the centres of such a frame the corresponding margins of both eyewires must be taken, and not the inner of one with the outer of the other, which might cause an error of 2 mm. Trouble often arises with these deep eyewires in fitting interchangeable lenses, for with a strong concave or deep convex there is of necessity considerable thickness in some parts of the margins, and the edges will there form a greater angle than those of the thinner lens. Consequently they will not enter the groove so far as the latter, thereby making the eyewire appear as if too small for the lens.

Straight sides vary from 125 to 136 mm. in length, the shorter being fitted as a rule to small fronts. In cases where longer sides are required for these or any other centres it will be observed that, when the frame is closed, the total length of the spectacle will increase by twice as much as is added to the usual length. Centres of 50 mm. will do with sides of 128 mm., while sides of 136 mm. will be full length even for centres of 64 mm. Curl sides need two measurements, the total length, and the distance from the joint to the bend, as shown in Fig. 124.

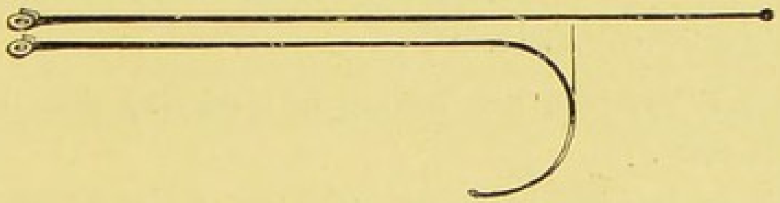


Fig. 124.

The small sizes of these are 125 mm. total length, and rarely more than 162 mm. are required for any spectacle. The difference between the distance from joint to bend and the total length is usually about 50 mm. Any size may be combined with almost any front.

Globular and some other tinted spectacles cannot be proportioned in the same way as are the usual types, and attention being devoted primarily to providing for a large eye, the other measurements and fittings must be adjusted afterwards.

For the measurement of clips with movable (swivel) plaquets details are necessary for the centres, size of eyes, and position of the plaquets. With given sizes of eyes the centres will vary with the distances of the contact parts of the plaquets from the eyewires, as explained in Chap. LII.

The length of the sliding bar determines to what extent the clip will open out, so that measurements are necessary for the space between the plaquets when closed, and also when fully open, otherwise the distance between may not allow sufficient space for the nose.

The projection of plaquets from eyewires may be determined by the distance between the inner plane of the eyewires and the centre of the plaquet surface. The position of attachment of plaquets to eyewires is taken from the centre line of the lenses, but usually they are put on at the centre line.

It is sometimes necessary to determine the tilt or "rake" of the plaquets from the plane of the lenses. They may be parallel, or, as more usual, with the upper part tilted inwards towards the eyes. Finally the width and length may be measured in millimetres. This last detail is especially important in clips and folders with fixed plaquets; moreover, the requisite contour or shape must be determined, and likewise the distances apart of the top and bottom ends, which will also indicate the angle they form with an imaginary vertical line drawn between them.

Summary :—

(*a*) With given centres certain sizes of eyes will be necessary for the best proportioned frames.

(*b*) Spectacle eyes are best defined by specifying their long and short diameters.

(*c*) With an increase in centres of 3 mm. a size larger in the lens is advisable.

(*d*) The space for the bridge is equal to the difference between the centres and the length of one eye of a spectacle.

(*e*) Curl sides necessitate two measurements.

CHAPTER XLIX.

PLIERS AND PLYERING.

TO the optician who would adjust frames to fit the face correctly pliers are indispensable. Many make an error in attempting to do too much with one tool, as several are necessary for accurate and careful work, the jaws of each being shaped in accordance with the use for which they are intended. Pliers which will grip a part like the parallel flat sides of a joint are quite unsuitable for holding and bending a rounded oval wire, such as is found in the bridges of spectacles. Some provision must also be made for holding the joints of folders and clips, as many of these are ball shaped or cylindrical, and flat surfaces cannot grip them firmly without damage.

Two points in the selection of pliers are worth consideration. The handles or legs must be sufficiently long to get a good leverage, and the jaws must be smooth inside, where they come into contact with the parts held by them. Usually pliers are roughened on these portions by the maker, the fine ridges thus produced preventing slipping over a smooth surface, but for plyering optical frames this is not permissible. To hold a finely lapped gold joint by such jaws would seriously injure the surface, and this damage must be avoided by using specially made tools, which are better nickelled, a surface being thereby ensured which will not abraze polished work, and will also prevent the pliers from rusting, if due care is exercised.

The most general use for pliers is in frame setting or straightening. All spectacles suffer, more or less, after opening the joints for the insertion of a lens, and when screwed up again may have the sides awry, causing the frame to sit incorrectly on the face. The commoner the frame the more frequently does this occur, due generally to some trifling displacement of the joint in the manipulation. A slight twist is then necessary to bring the joints into parallelism when closed over the lenses. To do this requires a pair of pliers whose jaws will close parallel on the joint, gripping it all over the part used, and not merely at one point, as in the ordinary shaped tool.

In this illustration four optical pliers are shown. No. 4 is specially adapted for holding spectacle joints, the jaws being so shaped as to close parallel upon any joint of usual thickness. Its utility is increased by the semicircular opposite grooves of the same size as the small joints of folders and clips already referred to. By placing this piece in the pliers the driver may be used without fear of twisting the eyewire, which is almost certain to occur if a refractory screw has to be turned without any holder.

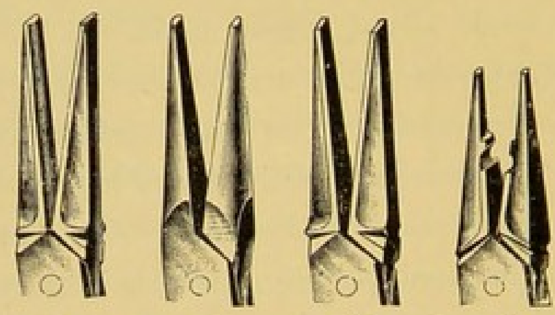


Fig. 125.

Pliers represented by Nos. 1, 2, and 3 are equally useful. The last has jaws tapering to parallel plates, the width of each at the extremity being 5 or 6 mm., and the thickness about 1 mm. These are used for gripping thin flat surfaces such as the "cranks" or "returns" of W bridges. The thin edge is much better than the thicker one of ordinary tools, for occasions arise when the ends have to be inserted between parts where the usual plier jaw would not enter. No. 2 is a similar tool called the "snipe nose," but the extremities are almost points, the contact surfaces being quite flat. It is a valuable adjunct in plyering bridges, especially where they are bent to form the "return."

The first form of jaws is different from any of the others, having a flat surface on one side, and a convex one on the other, known as "half round," so that when closed it presents the appearance endways of a curved edge against a flat one, both 5 or 6 mm. wide. Clearly this pair of pliers will have more wear on the one jaw.

Plyering is essentially adjustment, which may be the restoration of a part to its correct shape or position, or the alteration in form of some part for a specific purpose. In doing this the first consideration must be the metal of which the frame is made, various compositions under the names of white metal, solid nickel and alumnico, together with that variously described as gold filled, gold cased, or rolled gold being all more readily plyered than steel or gold. As they bend easily there is little fear of breakage during adjustment, and parts of frames can be shaped or bent into any such forms as the material will allow and the operator desire.

Steel and gold may readily be bent when soft. They are hardened either by being raised to a high temperature and *suddenly* cooled, or by being hammered, drawn, or worked when cold. The degree of this hardness denotes the *temper*. To temper steel which has been hardened, it is again gently heated and then *slowly* cooled, so becoming highly elastic. *Annealing* (as understood in the optical workshop) is done to make the material soft enough to plyer and bend. The metal is made red hot and slowly cooled. There is much annealing necessary in hand made frames to enable parts to be bent to the shape required.

Steel and gold require careful manipulation, due to the methods employed in making the frame. One made of steel has a peculiar hardness or temper, with all the elasticity characteristic of that metal, distributed according to the purpose to be served, and the better the workmanship the better tempered will be the parts upon which pliers are frequently used. With a highly tempered steel frame little should be attempted beyond "setting," but they are rarely so highly tempered as to resist all plyering, and many will be found amenable to the requisite handling for alteration of centres or bridge.

A frame which cannot be plyered will frequently bend under the pressure applied, but will not retain the shape, and when the pressure is released it springs back, so that this peculiar resiliency, when well developed, must, equally with a very rigid frame, be taken as an indication of an unplyerable article. Should an attempt be made and persisted in after these characteristics are shown, the limit of strain will be reached, and the part under tension will suddenly snap.

This precaution never has to be exercised in bending gold filled goods, in which the tendency of plyering is to bend the parts too much, on account of the softness of the material. Brass, or any similar metal which is used for the base, depends entirely on the draught of the tools or upon stamping and rolling to harden it, and being naturally a soft metal it is quite impossible to give it a high degree of hardness.

The white metals are frequently considerably harder, and are then very suitable for plyering. It sometimes happens, however, that certain compositions, probably from deficiency of tin, seem to be liable to a slight "case hardening" during the process of frame manufacture, causing trouble in manipulation afterwards. When bent, the first impression gives the idea of considerable resistance, but a sudden collapse is noticeable on a slight increase of pressure.

Gold is a perfect metal for plier work within certain limits. Plyering the ordinary form of crank bridges illustrates this, while many of the W type show how these limits may be exceeded, detailed consideration being reserved for the next chapter.

None of these metals have the same peculiarity at the breaking point as steel, for there is not the sudden snap which is noticeable in that metal at its best. Any of them can safely be bent from the straight to a curve, and generally from a large curve to a much smaller one, but to open out a small angle, unless very carefully done, means a breakage. The breaking point of gold is indicated by a sudden lessening of the resistance; the fracture is not always seen, and the parts when handled often appear still united, but actual separation takes place with any unusual strain.

Plyering necessitates a movement gentle and slow rather than heavy and rapid, both of the tool and the material. Sudden twists will often break a part, or cause a sharp angular bend instead of the regular curve intended, and no amount of opposite plyering will remedy the consequent unevenness of surface. This is most important, for any irregularities of surface at once suggest an improperly finished article. In plyering one curve to form another it is necessary to see that there is sufficient length of material to give the shape required.

Some parts of optical frames are quite unsuited for this method of treatment; chief among these are eyewires, curl and cable sides, and many forms of clip and folder plaquets with facings of cork or tortoiseshell.

In bending eyewires and sides (curl and cable) comparatively large curvatures are dealt with, and some tool approaching the same shape should be used. The thick round handle of a screwdriver will often suffice, pressure being applied by the fingers. If the eyes are to be made shorter and wider, very often gentle pressure on their two ends by the thumbs and first fingers of the hands will effect this. Pliers will not make a good curve of eyewire bent by them; moreover, there is great risk of crushing down and damaging the edges of the groove, which will then show a series of irregularities along its margins, particularly noticeable in a gold front with "lapped" edges of eyewires.

The improbability of a good curvature in curl sides is equally evident, unless some large body is used, around which to bend them, and for cable sides this restriction becomes absolute on these and other grounds. Cable sides have individual wires in them, much greater in length than the side itself, whether they are the true cable, made like a rope, or merely a series of coils closely wrapped round a central wire. These strands or coils are never parallel with the side, and in any part of it they are at a constant angle to that position. Hence with a sharp bend, while one part is being held firmly between the jaws of pliers, there is a tendency at some portion near for the strands or coils to separate, and so to permanently weaken or injure the whole side. But, if gradually bent around a handle of 1 inch or so in diameter this strain is distributed longitudinally, and no harm results.

Before screwing periscopic and sphero-cylindrical lenses of meniscus form into an eyewire it is better to give it a curvature approximating the shape of the margin of the lens. A gentle bend upon a rounded wooden door-knob held in the vice will effect this, but a slight plyering of the joint backwards is advisable, otherwise it will appear tilted inwards, and the sides will also be slanting toward each other. Constant strain in putting on and taking off spectacles by means of the sides opens these out, and forces the joints outward from the face, in addition to causing various bendings of the frame. To make the spectacle "true" again *setting* is required, necessitating use of the pliers. The joints and sides must first be restored to their correct position from the strained one referred to, by grasping the front and back of the joint with pliers, and gently twisting it inwards, *having first removed and ticketed the lenses.*

The lateral surfaces of the joint are then held, preferably by the special joint pliers, and the whole raised, as illustrated, before one eye. The eyewires must be brought into one plane, and the sides into another vertical to it, unless the joints are "angled."

Fig. 126 presumes that a straight line from joint to joint passes through the eyewires ; if this is seen not to be the case, probably the bridge is bent, and attention must be given to that, and alignment produced, before proceeding further.

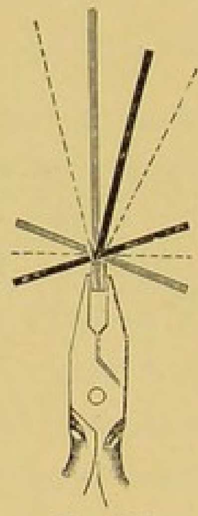


Fig. 126.

For the sake of clearness the parts are shaded differently, and the sides are made unequal. The black lines represent the eyewire and side nearest the eye. Aligning the eyewires to the dotted horizontal line, the sides will appear in the positions of the dotted lines, at smaller angles with the horizontal.

The first movement must be to bring the two eyewires into one plane, so that one "covers" the other, looking along them. Evidently, in such a case as represented, both must be carefully twisted into the horizontal by thumb and finger of the left hand, but the result will be that the sides will often appear still further apart, as indicated by the dotted lines. Careful examination will show that somewhere in each side, probably near the joint, there is a bend, frequently where the side is inserted into its "stop," which works round the joint. Correction of this should bring both sides into the perpendicular, unless the joint is "angled" for reading purposes, in which case the angling must be allowed for. Setting is not completed if on closing the sides they do not fold accurately one on each side of the opposite joint.

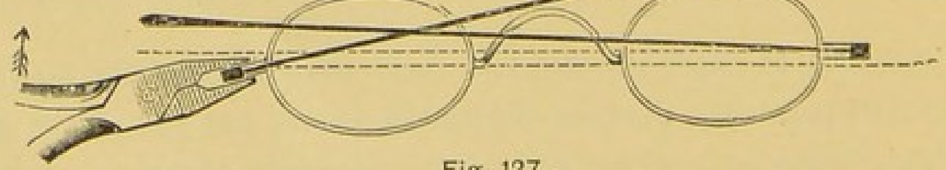


Fig. 127.

The dotted lines indicate the positions of the sides when correctly placed.

Fig. 127 illustrates this, and after straightening the sides by the former procedure, the cause will be evident from some irregularity of position of joint, provided the eyewires are symmetrically placed.

Using the same pliers in a horizontal position on the sides of the joint, a slight twist will adjust the spectacle sides so that they fold properly. Again the open frame must be raised endways before the eye, and if both sides are in a vertical plane the frame is "set" and true.

As these final adjustments have to be made *with the lenses in*, every movement must be slow and well judged to avoid chipping them. If the spectacle with sides open be placed edge down upon a smooth surface, the tips or ends of *both* sides should now touch that surface.

Summary :—

(*a*) Pliers must be strong, firm, and with smooth jaws.

(*b*) Using unsuitable tools involves injury to the frame.

(*c*) Highly tempered steel frames cannot be plyered.

(*d*) No suspicion of weakness must remain after plyering a gold frame, it means a concealed breakage.

(*e*) Plyer slowly and accurately.

(*f*) Do not use pliers on eyewires, curl or cable sides, or certain forms of clip and folder plaquets.

CHAPTER L.

SPECTACLE BRIDGES AND THEIR ADJUSTMENT.

THE various forms of bridges have been already alluded to in Chap. XLII., where, in combination with different patterns of sides, etc., their use for various purposes was described. Below are illustrated most of the varieties which the optician is likely to encounter, with their names attached.

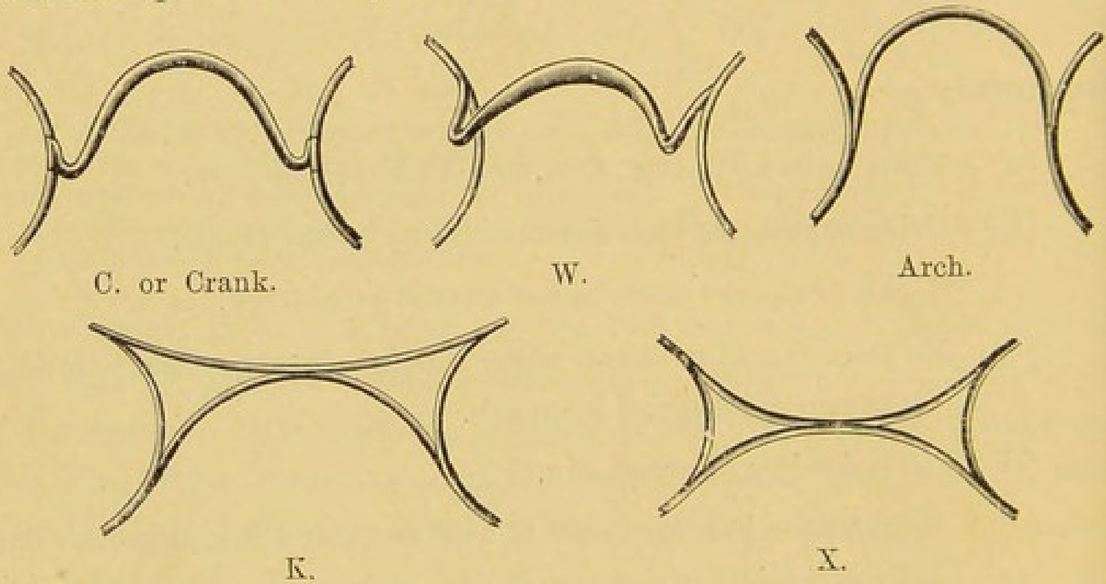


Fig. 128.

In all these cases certain parts are designated by particular names ; each has in the portion fitting on the nose, *sides*, and *apex* or *crest*, the lower parts of the sides indicating the width of the space called the *base*, while the upper portions merge into the apex. In the W. bridge, prolongations of the sides form what are termed *shanks* or *returns*.

All these bridges may be made of various metals, with different shapes of wire, the simplest being quite round, but to prevent marking the skin where the crest rests upon the nose many are flattened out over that portion to a greater or less extent, as may be required for comfort or appearance, the W so treated being frequently called a *saddle bridge*.

The principal forms now in use are the three first, and as the arch is rarely used except where the greatest possible space is needed for the nose, more especially when centres are small and the lenses large, we propose to confine our attention principally to the C and W bridges.

These may be shaped, by hand or machine, from a straight strip of metal of varying thickness according to the stoutness required. England produces by far the finest fitting and best shaped of the hand formed, while America is the home of the machine made type. The advantages of the hand made bridge are the greater variations which can be produced in contour and shape of parts.

These remarks apply to steel and gold. The gold filled article is especially suited to American methods of manufacture, and such a bridge cannot be filed, as this would destroy the casing, and expose the filling of base metal, nor can it be hammered safely, through risk of cracking the casing. It is shaped by machine, the finished bridge depending on the draught and stamp for its hardness. A gold bridge has different characteristics when made in different countries. As previously explained, it is bent and hardened, a quality imparted to it by drawing through a plate or tool, hammering or stamping, and burnishing. German made gold bridges are softer, having less labour spent upon them, while the American, being stamped, are also less reliable than the English made bridges.

Gold linings are sometimes put to steel and white metal bridges, a thin plate being shaped to the inner surface and soft soldered on, and, if required, a gold or gold filled bridge can be fitted to a steel frame.

A crank bridge may be attached to the eyewire by a "*curl*," which is the end of the bridge wire curled up and grooved for reception of the eyewire, or it may be put on "*straight*," the same portion being merely bent to the horizontal, and its end slotted. The W bridge may likewise be put on the eyewire in two ways, the leg or shank having a small groove made in the wire near the end, and fixed before brazing, by being "knocked on" as it is called, or the same part may be prolonged as a tapering thin strip of wire, which is soldered along its full extent to the eyewire, forming a "strapped," "tied on," or "spliced" bridge.

The W bridge is capable of being adjusted for almost every conceivable shape of nose, and, equally with the crank, may be fixed to any necessary portion of the eyewire, but in fine work discretion must be exercised, when the strapped W is required, as to whether the strap portion runs upwards or downwards. As this is bent at varying angles, the sharper the bend the greater is the strain, and consequently the greater is the risk of breaking or weakening it for wear. When the bridge is put on with its shank joining the eyewire above the central line of the eyes it is wise to run the strap upwards, but when below, it is better carried downwards. Either in gold or steel very close and neat splicing is necessary to obviate the solder showing along the line of union after the frame is finished. This does not apply so forcibly when the steel article is to be nickelled afterwards.

Specifications of the distance of the crest above the centre line of the joints and its projection or recession from the plane of the lenses will insure the necessary *position* of the whole spectacle frame, but it will not insure proper contact between the sides of the bridge and the sides of the nose.

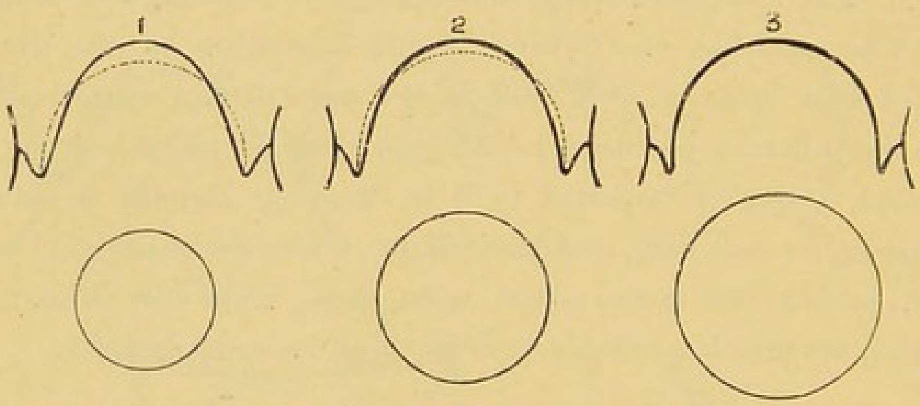


Fig. 129

Fig. 129 shows three W bridges, all 18 mm. spread and 9 mm. above the central line of the joints, the depth being 12 mm., but it is evident that in each case only one can properly fit the corresponding contour of nose. The actual crest of every bridge is the arc of a circle, and to adjust one form to another by plyering it is merely necessary to alter the size of the circle of which the apex forms a part. But no plyering of a bridge can possibly convert one form to another without altering the depth and also either the height or projection. The dotted lines in the figure illustrate what would be the effect on depth and height of altering the apices of 1 and 2 to the form of 3, presuming the projection to remain unaltered. But supposing the projection is greater than required, then by plyers on the shanks the body of the bridge could be pulled by the finger towards the eyewire, lessening the projection and increasing the height. A very necessary proviso for this operation is the existence at the crest of a shape of bridge-wire which will not present a sharp edge to the nose when adjusted in its new position.

Fig. 130 shows a W bridge which has the apex flattened out ; if this were brought nearer to the eyewire by bending, the upper edge only would touch the nose. Flattened bridges need some care, for the details of manufacture

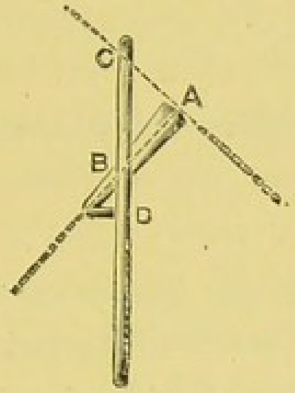


Fig 130.

A is the crest or apex of the bridge. D shows the union of shank to eyewire. A B is the slope or rake of the bridge. C A shows the angle of the crest with eyewire.
C A, and A B, are at right angles to each other.

necessitate certain positions for the shanks on the eyewire, with a given angle of crest. This applies particularly to gold filled bridges, which are stamped out, and to gold, which are bent with pliers ; steel admits of some latitude perhaps, but the rule applies even here to a great extent. Suppose that we have a gold, gold filled or steel wire in a *straight* piece, with the more flattened portion in the centre. The first bend to form the bridge turns up the bridge sides at right angles, so that if the centre be laid horizontally the sides will be in a vertical plane. These parts are oval wire (in section) if the crest is flattened, and such an oval wire can be bent most satisfactorily in the direction of the short axis of the oval section. Consequently, if a very high bridge is needed, the shanks must be put on higher up, for if placed lower (the depth of the bridge being greater to get the same height), they will alter the angle of the crest.

If the shanks are put on in a constant position (in most American frames these are at the central line), *they will have to be lengthened to allow for a correct angle of crest in a high bridge.* Long shanks, causing an extra and superfluous depth of bridge, are to be avoided in fitting. In flattened W bridges, then, generally speaking, the slope of the bridge is at right angles with the direction of the crest flattening. Better contact of crest and nose is assured in such a bridge by having the shanks so attached to the eyewire as to obtain the necessary angle of crest, rather than by an arbitrary attachment at the central line or other fixed position. A very convenient shape of bridge wire is one about 2 mm. across, and quite rounded on the inside, this giving the necessary rigidity, a most important point, for on the rigidity of a bridge and its attachments to the eyewire *depends to a great extent the stiffness of the whole frame.* Further, a wire of this shape can be altered in height and projection, within ordinary limits, without bringing any sharp edges against the nose.

In English made gold and steel frames, by extra labour in filing, almost any shape, with any attachment, can be obtained, but use of this latitude is rarely necessary.

If centres need alteration, and two frames are available, one of which is too narrow and the other too wide, both having the correct base of bridge, it is better to lessen the wide one by plyering the shanks inwards than to move those of the other outwards, for plyering inwards is merely a continuance of the process employed in manufacture ; plyering outwards invites a breakage by reversing it.

The correct point from which the height and projection of a flattened bridge must be measured is the inner *central* point of the bridge wire at the crest, for if we imagine the flattened portion reconverted into a round wire, and this filed down to a very thin strip, the centre of that would occupy the position defined, and both would fit the same nose. If the bridge has a tortoiseshell or cork lining, the same argument applies, and this lining must be allowed for. Crank bridges with no projection will rarely fit any nose.

Only W or "snake" patterns are available for receding or "inset" bridges, and the snake, being merely a W with an additional twist in the shank at right angles, serving no useful purpose, is generally ignored in modern frames.

Summary :—

(*a*) Hand-made bridges secure the best fit.

(*b*) The steadying effect of the sides of a bridge is very important, and demands attention.

(*c*) The full measurement of *bridge contour* only involves three details : (1) The apical arc radius. (2) The depth of bridge from apex to base of sides. (3) The width of basal opening between the sides.

(*d*) It is better to have a W bridge fitted on to the eyewires where it is indicated by the exigencies of manufacture rather than to specify an *untried* position.

Chapter LI.

SIDES AND JOINTS OF SPECTACLE FRAMES.

IT is necessary to consider these two parts of a spectacle together on account of their intimate connection, the side holding the frame on the face, and the joint serving the double purpose of a lock to hold in the lens, and a hinge to allow the sides to fold when the spectacle is not in use.

The various kinds of "sides," "springs," or "temples" were described in Chap. XLII., but we must consider the matter more in detail here, taking the straight side first. This in its commonest form is stamped from a thin sheet of metal, Fig. 131 showing the shape generally used.

Fig 131.

The two ends are not alike, one being more or less rounded or oar-shaped, and the other an oblong, with a small similarly shaped hole in the centre. This hole receives the small projection on the drilled circular piece of metal shown, which is rivetted on to the stamping, the oblong end being curved round the circular piece at the same time. The small circular piece forms the "centre-bit," which fits into the joint, while the oblong part of the side proper forms a butt or "stop," and prevents the side opening out too wide. This form is mostly foreign, few English sides having a rivetted centre-bit.

A similar stamping is much used in American sides by utilizing the piece at the joint end for the centre-bit. it is then made round, except for a small projection forming a stop, and has a circular hole like the one shown above, but it must be at right angles to the oblong portion of Fig. 131. This is known in America as a solid side, in contradistinction to the rivetted one. English straight sides may be either stamped (by far the greater number being so formed), or forged out from a thicker and shorter piece, the extremities being left large to allow of the tips being shaped at one end, and the stop and centre-bit being worked upon the other.

Portions are cut away from each side of one solid part by countersinking, thus leaving the stop of the correct shape on the inner side, at the same time forming the centre-bit. A side made in this way is stronger than any with the centre-bit merely rivetted to a stamped side.

A good class steel straight side is formed by hand to the shape and thickness required in different portions, that near the insertion into the joint being left somewhat thicker in the direction of the length of the front, to allow for greater rigidity, while the central portion is tapered down to give the necessary flexibility, by means of which the side holds on to the face. They are then hardened, and afterwards tempered suitably in boiling oil. Gold spectacle sides are hammered out, and hardened by working up to the shape required, the parts connected with the joint being hard soldered on.

Loop or open ends may be formed by stamping, or the metal may be split, the two parts being curved round and united into a loop by soldering their ends together. These ends grip the head better on account of covering a larger surface of the hair.

Various solid, "thickened," or "swelled" ends are put to sides for the purpose of allowing them to slide *smoothly* over the skin. They may be made by forging, or brass may be run on to the inner side of a steel end, both being filed up afterwards; the forged steel is preferable, as the brass may corrode and become unsightly. Spoon-shaped and turned-up ends serve the same purpose, a depression being punched in the metal in the former kind.

There is a great difference between the utility of a hand made side and a foreign stamped one, the former having the resiliency only where it is needed, with the stiffer part near the joint, consequently the hand made side "gives" along its central portion to the shape of the side of the head. In most foreign sides there is either uniform resiliency or uniform stiffness, the first defect being counterbalanced by an increase in length, which will not allow the frame to slip off; the second, having no remedy, causes the front to "ride," so that the bridge will not stay on the nose, but jerks upwards, owing to the grip of the ends of the sides both holding the frame on the head and taking the weight of the front off the nose. A side, when drawn between the fingers from the joint upwards, should offer no irregularities of form or temper to the touch, and will, when correctly made, indicate its varying elasticity by its movements when pressed between thumb and first two fingers. Straight sides should have a flat surface next the face, the outside being rounded (known as "half round springs"), giving much greater strength than an equal quantity of material in the flat form with square edges.

Curl sides are somewhat similarly made, but are drawn out to the approximate thickness required. The method employed in making the *commoner qualities* of cable sides, both in steel and gold, is to form a tube or "chenier," 1 inch to 1½ inch long, which is soldered on to the stop. The cable portion is composed of a single round wire core, about which a very fine wire is coiled, with the coils touching one another throughout its length. In many of these forms 4 to 5 feet of fine wire is required for a side, the whole being afterwards pulled through draw-plates to smooth the surface and compress the coils together, giving them at the same time a grip on the central wire. This cable is cut to the necessary length, and a small knob or cap soldered or pressed on one end, while the other is inserted into the tube, being made fast there by pressure around the opening, or by being soft soldered into it. The disadvantage of this form is the frequent breakage at the junction of cable and tube, for any pull sideways on one is apt to dislocate it from the other. A remedy has been found in the form of a cable wherein the central wire and its surrounding coils run right down to the joint, being hard soldered on to a prolongation of the stop or centre piece, according to the form of joint used. In the English steel cable the coiled wire, (or sometimes a true cable) is *spliced* on to a solid stump by hard soldering, and is, when well done, superior to any of the above forms.

None of these sides are "cables" in the strict sense of the word, for no true cable depends for its strength upon a central core, the fault of all varieties with coiled wire, for if the coils separate anyhwere, then the thin central wire alone resists complete breakage.

English gold cables have long been made by strands being twisted together, just as a rope is formed, and they rarely break in the cable portion, but being usually soft soldered into a terminal shoulder tube they are liable to bend at the union and eventually break off, although less frequently than the coiled forms. Hard soldering of the cable into the tube cannot be resorted to in gold work, as the necessary heat softens the parts which are already hardened. This has been overcome by splicing the cable on a stump of solid gold without softening the parts, thus forming a side with no weak place.

Sides have been made with a secondary hinge, about 1 to 1¼ inches from the joint, to allow the whole front to be tilted for billiard playing, rifle practice, etc.

The joint of a spectacle may be formed in many different shapes, ranging from the two small circular pieces of metal of about 2mm. diameter, with a single screw serving the double purpose already mentioned, to the peculiar form found on some goggles, where a rigid pillar of 1 inch or more is attached, approximately at right angles to the end of the joint, the side being hinged on the other end of the pillar. But for ordinary spectacles the joint varies in length, by which is meant the actual amount contributed to the front, from 3mm. to 12mm. or more.

The screw holding the two parts together is inserted in the joint between the eyewires and the portion into which the centre-bit of the side is fitted. Where an extra long joint is necessary two screws are advisable, one near the lens, and a second near the opposite extremity to prevent "gaping."

A space for the centre-bit is drilled out from both halves of the joint, one part of it fits into one half and the other into the opposite. This space is called the "joint countersink," while the two portions remaining, of the same size as the centre-bit, are known as *collets*. In the centre of each is drilled a hole, and a pin running right through secures the side to the joint. In British-made frames this pin is screwed into one collet and tapped on the outer side by a punch with a small point, which swells the metal around, thus making the pin quite firm and secure. The other end of the pin exactly fits into the hole of the corresponding collet, and this may be raised from it when the joint is opened. Upon the close and accurate fitting of centre-bit and collets depends the perfect working of the joint, and the consequent smooth and even wear of that part of the frame. The two halves of the joint should be of equal thickness, closely fitted together, and the pin fixed into the one collet should exactly fill the holes in both centre-bit and the other collet. The centre-bit must also be made to fill up the space allowed for it, fitting closely against a collet on each side. For reversible sides it is necessary to do away with the stop, the centre-bit being attached directly to the side, and the countersink so worked in the joint as to allow the side to swing right round the end of it.

Evidently neither centre-bit nor collets can be altered in diameter without both being rendered disproportionate, so that when a new side is fitted to a frame this must be attended to, otherwise, with a centre-bit too small the stop will not go outside the collets, or with one too large the stop will not touch them, but stand away, giving a very ugly appearance and much less rigidity to the side. It is very necessary to see that the centre-bit is of correct thickness for the space; one too thin will, if fitted, cause "rocking" of the side, and one too thick will not allow the two halves of the joint to meet.

What is known as the back of a joint is seen in front when the frame is being worn, and this part generally gives certain designations to joints. The simplest form is the *flat back*, sufficiently described by the term itself, and found in cheap American and Continental frames, a *short bevel*, being a grade higher, is filed up to form a ridge exactly on the dividing line. A *long bevel* is merely an extension of this, the screw and pin being further apart. By curving the back of the joint a *curved bevel* is obtained, which throws the collets inwards, and by increasing the curve a *cocked* joint results, where the screw hole is exactly in line with, and anterior to, the insertion of the pin, giving the shortest obtainable form where both screw and pin are used. In addition to these we have the *hump back*, a short bevel with a projecting portion by the screw hole, *ball joints*, either flat or bevelled, and various forms known as fancy *pattern joints*, in which the file is used to cut away superfluous metal, giving certain ornamental designs known as "*hollow backs*," *swan joints*, *double ball joints*, *&c.*

Plain bevel — Hump back — Cocked joint — Flat bevel — Fancy pattern.

Fig 132.

Occasions arise when these variations in shape may be used to advantage. In some instances deep concave lenses have edges projecting so much from the eyewire that a very short straight bevel will not allow sides to close and a tilted, curved or cocked joint is necessary. Those slightly curved inwards are preferable when reversible temples are used, for these will never close properly on both sides of a front, and are always better fitted into a joint allowing easy closure on one side only.

The thickness of joints (indicated by the total length of the screw) demands attention. Sufficient material must be left in the collets to resist strain on the sides, otherwise they will burst outwards. Gold joints cannot be made so thin as steel ones to give equally good results. In much German work, in which the joints are often made from one piece of metal sawn through, instead of two separate pieces fitted together, they are not properly hardened, and in many cases they are sawn unequally, so that one half of the joint is much thicker than the other, some even being sawn *obliquely* from front to back. Weakness of such joints is inevitable. A well fitted fine joint is always more satisfactory than a badly fitted heavy one, but a well fitted heavy one is indispensable for rough usage.

Screws should be varied in size and material to correspond with the metal of the joint and with the space available, a stronger thread being necessary for gold and the soft metals.

Angled joints, to give tilted fronts, have the eyewires inserted on the slant, so that the sides, when open, are at angles of 5°, 10°, 15° or more with the perpendicular to the plane of the lenses.

To test the fitting, a side is slowly opened and closed, the smooth and even motion indicating a virtue which a loose or jerky one shows to be lacking. A badly fitted centre-bit is often the cause of this jerky movement, for in some positions it will hold the side quite stiff, whilst in others this may be so slack as to fall by its own weight. Sometimes a stiff or irregular movement may be obviated in a steel joint harsh from non-use by the application of a minute quantity of oil, but this should never be applied to a gold frame, which calls for gentle warmth and the application by a small pencil of camels' hair of a thin film of beeswax dissolved in benzol.

Summary:—

(*a*) The strongest sides are made from solid pieces of metal.

(*b*) Loop or open ends are best for gripping the head, and save extra length.

(*c*) Sides must be stiffer near the joint.

(*d*) The twisted cable is less liable to break than the coiled variety.

(*e*) Centre-bit, collets, pin and stop must all fit well for good work.

(*f*) Certain forms of joint are sometimes better than others, even with the same frontal measurements.

(*g*) Use oil for steel work and beeswax for gold, when the joints are stiff.

Chapter LII.

THE ADJUSTMENT OF PINCE NEZ AND CLIPS.

IN these two forms of optical frames we are limited to consideration of parts which correspond to the eyes and bridge of a spectacle. The same precautions, so necessary in the position of a spectacle eye, demand equal attention here. Fixture on the face depends on some form of *plaquets* for gripping the nose, and the tension required for that purpose necessitates a different position at rest from the one assumed when under the strain required for wear.

The primary consideration in all these cases is the horizontal position of the lenses when in front of the eyes. In the group known as folders, when the frame is open and worn the long axes of the lenses will be at right angles to the position assumed when they are folded.

The spring is put to its greatest tension when the frame is locked, one eye exactly covering the other, an essential feature of the correct folder, the *catch* of the one being held securely by the "*catch pin*" on the handle of the other.

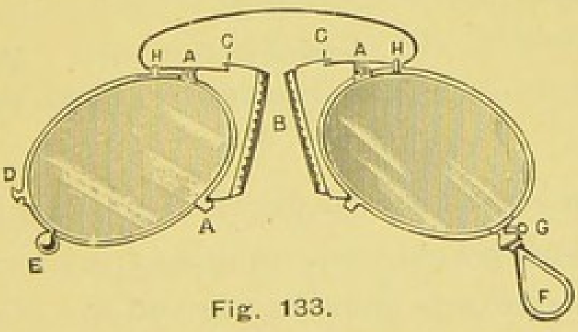


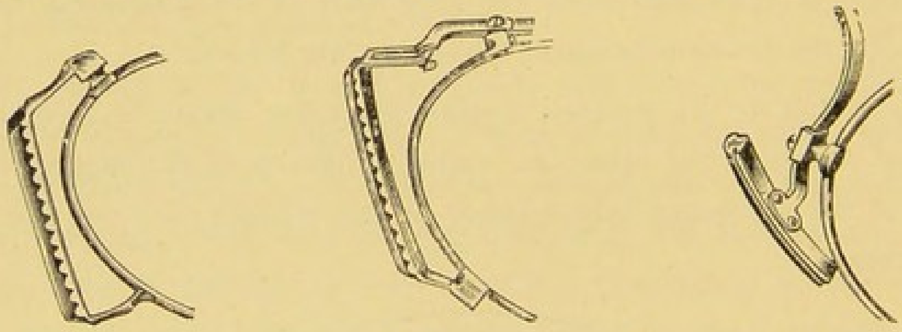
Fig. 133.

A. Studs or Holders. B. Plaquets. C. Plaquet bits or T. pieces.
D. Catch. E. Screw Holder. F. Handle. G. Catch pin.
H. Ties or Springloops.

Two factors influence the covering when closed and the horizontal position when worn—the length of spring and the position of studs or attachments of this to the frame, which are constant for a given position of handle and catchpin, but if these are put on a different part of the eyewire, then the studs must be rearranged.

The forms of plaquets (parts which grip the cartilaginous portion of the nose) are very varied. They may be attached at both ends, as in the Japanese pattern and various spur types, at one end, as in the Canadian and "perfection" folders (in the last being a continuation of the long form of spring, which is held down to the eyewires merely by the "ties" or loops through which it moves freely), or they may be attached at their centres, as in the swing plaquets so noticeable on various clips.

Whichever of these is used it must be the correct shape for that portion of the nose it is intended to fit. Few forms with a convex surface towards the nose will secure equal contact over their full length, but if the plaquet be made straight, or even concave, having in either case longer spurs from the eyewire both at top and bottom, comfort can be secured. The centres of lenses can be adjusted in these forms either by a larger eye or by a greater extension of the plaquets away from the eyewire, as in many spur types. For very small centres, where little space is available between eyewire and plaquets, the "pear shape" may be adopted.



Straight spur plaquet. Angled or inset Canadian. Fixed plaquet with single attachment.

Fig. 134.

With some clients one lens always sits higher on the face than the other, often due to an irregularly shaped nose, requiring special adjustment of plaquet form. If one lens projects from the face and the other is too near, it is caused by the folders or pince nez being strained, and when the frame is held endways before the eye it will be seen that the two lenses are not in the same plane, due to the eyewire of one or both being bent away from the studs, or the spring may be twisted. The remedy is to adjust the eyes or twist the spring sideways in the contrary direction from that of the defect, until the parts entering the studs and the upper reach of the spring are perfectly true in respect to each other.

The studs should be equidistant from the upper portions of the spring to which they are opposite, and the lenses so screwed into the frame that they will sit horizontally when on the face. Any tendency of folder or pince nez lenses to "droop" is objectionable.

Angled or inset plaquets may be made in any form of folder; a spur is attached so that the upper portions project towards the face, fitting further on to the nose. They are always more or less troublesome and in the way when frames are intended for folding.

Certain pince nez (both framed and frameless) with a shorter and stiffer spring than a folder are often much used. These do not fold, but sit on the face with the lenses in nearly the same position as when at rest. The forms of plaquet are very numerous, some being lined with cork, others with shell, and a third being merely a thin sheet of metal adaptable to the contour of the nose by bending. All are made broader, thinner and flatter than folder plaquets, and are generally inset. In giving measurements for such frames it is necessary to specify size of eye, centres of lenses and distance apart of plaquets at the upper and lower extremities.

The fault of most of these frames is the instability of the attachment of plaquet to stud. Setting and adjustment are done in precisely the same way as with folders, and their flattened thinner guards are more amenable to plyering than the ordinary folder plaquets.

In all forms of eyeglasses the plaquets must be so adjusted as to obtain a slightly firmer grip upon the nose in the upper parts, otherwise the weight of the lenses will often cause them to tilt forwards and fall. Hence in fitting an eyeglass frame on the face it is advisable to place lenses in the eyewires.

It sometimes happens that the length of a spring requires alteration. An arched one can be lengthened by depressing the curve, and then with the half round and flat jawed tool increasing the curve near the attachments. In the case of a long spring with a long return, if lengthening is necessary, each bend into the top part must be opened out, throwing the eyes away from the spring, when a new curve nearer the attachments will bring each eye up again, with the plaquets further apart.

In clips with sliding bars it is advisable to have these parts long, for this insures a more evenly distributed tension in the coiled wire, and will allow the lessening of pressure by the removal of a few coils. There is also less risk of sudden breakage at the extremities. Harshness of movement of the bars must be remedied by straightening and adjustment rather than by oiling, which should never be resorted to in gold or gold filled articles on account of the objectionable black deposit formed. With a given size of eye centres may be widened by the lengthening of the plaquet stud, and in cases where inset or receding plaquets are required a collar should be put upon the plaquet pin.

Should the shape of the eyes be altered from long ovals to shorter ones, or vice-versa, the plaquets will be in a relatively different position, and this must be allowed for.

Sometimes it is necessary to have the bars attached further from the plane of the eyewire (or outset), to avoid contact with the face, but this will always increase any tendency towards tilting.

When the lenses are out of their true planes it will generally be found that the eyewires are strained at the points of attachment to the bars.

Summary :—

(*a*) Lenses must sit straight on the face in all forms.

(*b*) It is better to have special plaquets made than to attempt to alter many of the existing forms.

(*c*) Weaken a bar spring by the removal of a few coils, oil as little as possible with steel, and never with gold.

CHAPTER LIII.

EXAMINATION AND USE OF PEBBLE LENSES.

ALLUSION has already been made to the slight variation in curvatures between pebble and glass lenses of the same focus, the stone being denser than glass, with greater hardness and a *higher* index of refraction. There is a further difference, for glass is a manufactured product, and can be formed into any shape desired when molten, whereas pebble is a natural stone known as quartz or rock crystal, similar in some respects to the diamond, and found in definite forms of greater or less bulk. These are crystalline, and always of the same general shape at their ends or solid angles, although varying much in size. This stone is chemically known as silicon dioxide, or silica ($Si. O_2$), and in a modified form is found as amethyst, opal, flint, etc., the two last being non-crystalline. Its specific gravity is 2·7. It is the most widely distributed mineral, the fine colourless grains in sand and granite being practically pure quartz. Acids do not affect it. Quartz belongs to the hexagonal system of crystals, each crystal being composed of a six sided prism, ending at each extremity in a six sided pyramid. The sides may not be equal, and sometimes the angles are cut away by a small facet or face, although in the perfect type all the sides of the body are equal, and the sides of the pyramidal ends also. There are thus four lines which can be drawn denoting the "axes of crystallization." One from end to end is the primary axis (A. B. of Fig. 135), the other three being formed by joining the diametrically opposite edges of the sides of the crystal. Such a crystal is symmetrical about its axis, and is known for *optical purposes as a uniaxial crystal.*

Pebble is found in many parts of the world, but is commercially most valuable from Brazil, being exported thence in goat skins, which are sewn up whilst in a damp state, hardening and shrinking around the stones inside as drying proceeds.

All crystalline bodies which do not naturally assume a cubical shape are doubly refracting, so that when light enters it travels in two separate directions. Even in the cubical system of crystals and glass double refraction can be produced by unequal compression, or by sudden cooling after being heated, so that if glass is improperly annealed double refraction results.

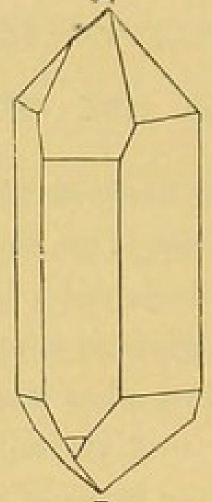


Fig. 135.

Various crystals are doubly refracting in different degrees and positions. Uniaxial crystals are *singly refracting* along the principal axis, which is known as the *optic axis* of the crystal, and *doubly refracting* along any other line not parallel to it. Every line parallel to the central one is equally an optic axis, so that the expression indicates a direction rather than a single line, and the path of light meeting pebble in any other direction becomes double, these paths being known as *ordinary* and *extraordinary rays*. Of these, the ordinary ray obeys the well-known laws of refraction, but the extraordinary only partially obeys them.

With crystals of some substances, notably Iceland spar (calc-spar, chemically known as Calcium Carbonate $Ca.Co._3$) two images will be seen when looking at a dot upon a sheet of paper placed beneath. Revolving the slab the extraordinary image circles round the ordinary and appears further off. Pebble will not exhibit these phenomena, owing to the extraordinary ray being very weak on leaving the crystal, even when it is used in the most favourable position.

A section at right angles to the axis of a crystal provides the surface which is best in every way for the purpose of lens making, and a slab cut in this position is used in the manufacture of what are known as *axis cut* or "*axe*" pebbles. The great superiority over slabs cut in any other direction (from which the ordinary "*non-axe*" pebbles are made) is that for *parallel* incident light there is no double refraction. Very few eyes suffer any inconvenience from the extraordinary ray in the non-axe pebbles, but occasionally cases are met with where it becomes troublesome, especially in strong powers and some periscopic forms.

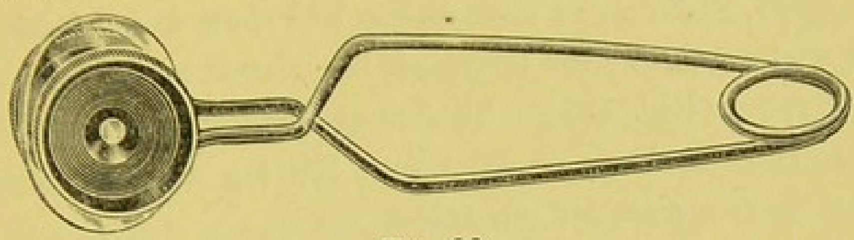


Fig. 136.

To distinguish pebble from glass lenses, and also to divide axis cut from non-axe pebbles the "tourmaline pincettes" are used. These are so called because of two thin plates of the semi-transparent mineral tourmaline, which is primarily a hexagonal prism similar to a crystal of pebble with the ends cut off; it is also uniaxial, but is unlike pebble in so far as its index of refraction for the ordinary ray exceeds that of the extraordinary ray, whereas with pebble the contrary is the case. The small plates of tourmaline in the "pincettes" are cut *parallel to the axis of the crystal*, and so arranged that they can be turned round, the one axis lying parallel to the other, or exactly across it, for puposes of observation. With the axes parallel, on looking through the sight hole at a white cloud, a greenish light is seen, but with the axes at right angles very little light passes. The slab away from the face acts as a *polarizer*, and the one next the eye as an *analyser*.

When a ray of light passes into the polarizer it is divided into an ordinary and an extraordinary ray, but tourmaline, if thick enough, rapidly absorbs the ordinary ray, and only the extraordinary ray is transmitted, in a condition known as "polarized," so that if the analyser is in a parallel position with the polarizer it will pass through, with loss merely due to thickness, but if the plates are at right angles it cannot pass, and no light is seen through the instrument. Glass being inserted between the plates cannot alter this, but with pebble, itself a doubly refracting substance, it is different. It depolarizes the light when used in certain forms and positions. With a "non axe" pebble there are two positions in which it will have no effect, and two others at right angles to these where it will cause most light to pass, the field being of the greenish colour mentioned. Between these positions the intensity of the light varies from brightness to darkness as the pebble is revolved around its geometrical centre, the *pincettes* being kept stationary. With axis cut pebbles the phenomena are different, for they will allow light to pass equally for any position of the lens. Moreover, a series of beautiful concentric circles is visible round a clear circular space, and careful observation will show a *faint* darkness in the form of a cross right over the rings, but almost invisible where it crosses the clear space (Fig. 137). This cross undergoes curious changes when one tourmaline is slowly moved round, keeping the other and the pebble fixed, but these are beyond our subject.

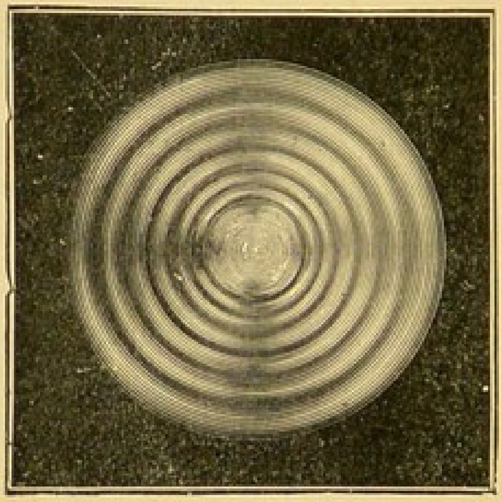


Fig. 137.

The concentric circles, when perfect, are *indicative of an axis cut slab*; the clear space must occupy the centre of the field, and if to one side or absent, when merely arcs of circles will be seen, the pebble is not *truly* axis cut, but varies from it according to the faintness and wideness of the curves of the arcs. "Axis cut" are more expensive than the "non-axe" kind, as much greater care is necessary in cutting the slabs, and the material cannot be used to advantage.

Pebbles absorb more heat than glass, and consequently when *first* touched by the tongue, which is so sensitive to change, heat is taken from it, and the pebble *seems* momentarily colder. It is also harder, and a file used upon the edge has no effect except to damage the teeth of the tool, whereas glass may be filed readily. This extra hardness of pebble is of some value. The lens takes in consequence a very high polish, and cannot so readily become scratched. Hence for some presbyopes, who are constantly removing their reading or working spectacles and placing them upon hard surfaces, pebble lenses are an advantage, for with lenses made of fine glass scratches are very readily formed on the surfaces.

Pebble lenses, whether "axe" or "non-axe," need careful scrutiny to detect the many possible imperfections. They may be ground from crystals which have a decidedly dirty brownish hue or are unequally transparent in different parts. In axis cut pebbles this blemish will sometimes run merely from one surface to the other, appearing as a streak on the face of the lens. A sheet of white paper in daylight will detect colour if the lens is examined from different points of view. Occasionally a slight vein of colour will run through the material as a faint band. Heat will change these colours to a yellowish tint, which requires more careful scrutiny for its detection.

Striæ or lines are very common and are more pernicious. They may be seen by moving the lens about between the eye and a good source of light such as a white cloud, and are frequently evident in reflected light when the lens is held over a dull surface. Similar appearances are caused by the effects of lamination, the material seeming as if composed of a series of regular or irregular plates. Sand marks are minute particles or holes in the body of the material, and frequently peculiar ribbon like bands composed of fine sand marks loosely aggregated are discernible.

Specs and scars on the surface must be carefully sought for, and need discrimination for their correct appreciation, for pebble being a substance readily electrified when rubbed at once attracts to its surface any particles of dust and other small matters floating in the atmosphere or attached to the rubber with which the lens has been wiped. Consequently it will often appear to have small marks on the surface, but these, if due to friction, will be moved by the application of the finger, whereas any imperfection is permanent.

Irregular polishing sometimes gives a peculiar rippled or wavy appearance, and any pebbles so affected should be at once rejected. All lenses should be as thin as possible to obtain the best results.

Summary :—

(*a*) Pebble is a doubly refracting uniaxial crystalline substance.

(*b*) The axis of a crystal is a direction along which a ray of light passes without undergoing double refraction.

(*c*) Lenses ground from slabs cut truly at right angles to the axis are "axis cut" pebbles.

(*d*) The "tourmaline" enables us to discriminate between glass, "non-axe pebbles," and "axis cut pebbles."

(*e*) Pebble does not become scratched so readily as glass, and should be examined for colour, striæ, waviness of structure or of surface polishing, and sand marks.

Chapter LIV.

SPECTACLE GLAZING, GOOD AND BAD.

THE tools and appliances used in reducing and grinding lenses for fitting into frames have been described in Chapter XLIV. Their employment needs some attention, for a knowledge of the process is advisable in order to thoroughly understand the examination of work already done.

Lenses are made from various kinds of glass, and those considered of low grade are harder than the whiter varieties, which have a greater proportion of lead in their composition. The increase in whiteness of material is made at the expense of hardness, hence the necessity for careful handling in glazing, as small particles from the lens itself may in shanking get between the thumb and glass, causing scratches at every movement. Again, unless the water used with the stone is tolerably clear, the fine sand from the latter will do precisely what the small glass particles did in shanking, causing marks and fine hair-like lines. The thicker the lens the greater liability there is to these imperfections, owing to the longer period of working.

Nothing but practice will give proficiency in the peculiar scissor-like action, with the necessary twist of the hand, which snips off particles of glass from the edge of the lens until it is approximately the size required. When finely shanked and tried in an eyewire of ordinary calibre, about $\frac{3}{16}$ of an inch apart for the joints will allow for the necessary grinding, but more margin must be left unless the worker is proficient. To save opening the joints, if the lens be made to the size of the outer edges of the eyewire it will grind down about right. Convex lenses in the rough should be chosen of different sizes for varying calibres, that which is suitable for 0 and 1 eyes, about 40 × 30 mm., will frequently be too thick for 2 and 3 eye sizes, if the powers are above + 2·00 D., but for concave lenses one size of lens will do for all purposes. There is art even in holding a glass for shanking ; if the finger and thumb are far removed from the cheeks of the shanks, when reducing a concave, the strain on the thin centre is too great, and the lens snaps across. To avoid this it is better to grip the lens on the same side of the centre as the tool is used. Concave and mixed sphero-cyls. are peculiarly liable to breakage from this cause. Tinted glasses also need care, on accound of their brittle nature.

If a diamond is employed to cut away superfluous glass before grinding, a series of eyesizes should be used as patterns, round which the point is drawn once only. These may be of wood or some other material which will not slip readily on the smooth surface, and they will naturally require to be smaller than the line made, the difference depending on the shape of cutter used. The edges can be broken away very sharply, and with proficiency great exactness of size can be secured, but the greatest care must be exercised to keep centres and axes in their correct position during marking. This precaution applies equally to shanking, and where a great variety of shapes and sizes is necessary, shanking probably secures a shape more exact to a special frame than does the use of an improvised shape and a diamond.

To insure the correct position of a cylinder axis a strip of gummed paper placed in the exact horizontal position (joint to joint) of the eyewire, with the point that is to be the final geometrical centre marked on it in ink, is all that is necessary. Faber's glass pencil is also convenient for axis marking.

Before periscopic, globular and many cylindrical lenses are ground the eyewire, if not already shaped, must be bent to the curvature required for the edge. Some knowledge is necessary of the temper of the steel forming the eyewire, for it often happens that a lens, imperceptibly too tight, may, in a very stiff and harsh eyewire, with a fall in temperature, crack or splinter after it has left the hands of the workman. Some American and German steel spectacles are peculiarly liable to this, but gold and gold filled are almost exempt. Where brass has run into the grooves during brazing, and has not been properly cleared away, a cutter may be employed, illustrated in Fig. 138.

When the lens has been shanked to *exactly the same shape* as the eyewire, it will be observed that the edges are not the same thickness in all parts. In an oval convex spherical the edges will be thinner at the ends near the joint and bridge, and thicker at the top and bottom ; in a concave spherical the reverse will be the case. In cyls., sphero-cyls., prisms and prismatic combinations the thickness of the edges will vary with the position of the axis of the cyl. and the base of the prism—all these points must be noted before grinding, for it is essential that the V edge shall lie as symmetrically as possible all round.

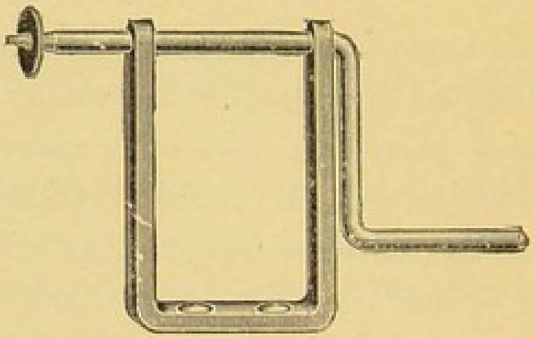


Fig. 138.

The first part of the process of grinding is to take off the rough edges, thus commencing to form a V edge by holding the lens between the thumb and first two fingers against the edge of the stone, keeping the thumb downwards, and the lens at about 60° with the vertical. This prevents any chipping of the edges in the later stages. Holding the lens now at an angle of about 45°, and moving the glass from side to side in the groove, giving several such movements to every turn of the handle, whilst exerting firmer pressure upon the stone, will grind one side of the V, and reversing the lens will cause a similar cutting of the other side. Evidently the thickest part will require most grinding, and the lens must be *moved round* between fingers and thumb while still on the stone to insure a cutting over the whole edge, with more work on the thicker parts. If the thin edges are ground too much the lens will be altered in shape, and probably also in size. Nothing but practice will give uniformity of bevel and a *continuous* and even edge all the way round.

All this must be done on a quick cutting stone ; it would take far too long on a slow, smooth cutter like the Craigleith, which is brought into requisition merely for finishing the edges and giving then a dull smooth appearance.

It is unwise to use stones for other purposes, such as grinding tools, and the Craigleith must be particularly guarded from such treatment, as this interferes with its utility for some time after.

Grooving lenses to fit "invisible" eyewires is done on a copper or iron disc, about 6 inches in diameter, run in a lathe, the edge corresponding to the size of the groove required. The lens, after shanking, must first be made flat on the edge by grinding on the side of a smooth stone, and given a slight bevelling to avoid subsequent chipping of the margins. This flat edge is then held against the grooving wheel so that the cut shall be in the centre.

There are many points to be considered in the examination of work received from a glazier. Lenses are made from *white* and *extra white* glass, the latter being softer because of a higher percentage of lead in its composition. The extra white lenses are further divided into *fine* and *half-fine* by selection after surface grinding, perfect freedom from marks putting them in the first class. Very rarely will a fine lens retain its character unless very great precautions are exercised. Examination by gaslight invariably shows some minute marks, owing to the softness of the material. Friction by the dry hand is even sufficient in some cases to produce surface marks on such a lens. Any blemish clearly visible *by daylight* should disqualify a lens.

If the R. and L. eyes require different corrections examination is necessary to see that the lenses are placed in their own eyewires. If there is any choice in surfaces, inner and outer, this also must be observed, and also a measurement of centres made, to see that no rounding or elongation of the eyewires has resulted from incorrect shanking. The lenses must be perfectly horizontal in the frame.

Examination for correct centering should be done by viewing cross lines, and if a cylindrical element is present the axis must also be determined and marked. A reference to the actual lenses ordered is necessary when neutralizing, and for determining the correctness of the meridian of the axis of every cylindrical lens.

This is done by means of a protractor, with degrees marked the reverse way from the ordinary prescription form, so that the front of the frame may be laid downwards upon it.

The lens should not move in the eyewire when grasped by the thumb and first finger of one hand, whilst the joint is held similarly by the other. No marks should be visible on the smoothed edges, and the V shaped margin must be gripped securely by the eyewire.

Summary :—

(*a*) Grit and lens dust must not scratch the lens in shanking.

(*b*) The grindstone should be used for glazing only, and the water kept clean.

(*c*) Care is necessary in shanking concave lenses.

(*d*) Eyewires need examination before lenses are screwed in.

(*e*) Lenses must be cut to the shape of eyewires.

(*f*) Examine glazing for (1) Quality, colour and thickness of glass. (2) Fineness of polish and freedom from scratches. (3) Centering (and axis) of lens. (4) Power of lens. (5) Position in frame. (6) Quality of glazier's work and accuracy of fit.

CHAPTER LV.

BRAZING, MATERIALS AND METHODS.

BRAZING, in the correct use of the word, means the joining together of two pieces of metal by means of molten brass, and is merely an intimate adhesion of the brass with the two parts joined. This is quite distinct from an alloy, in which two or more metals are mixed when both are in a molten state, or an amalgam, where the one metal is absorbed or incorporated by contact, as mercury and gold. For our present purpose we regard brazing as the union of metallic parts by any *solder* which is similar in its action to brass and melts at about the same temperature, generally near 1600° Fahrenheit.

The only solders which the optician need consider are brass itself, silver solder and gold solder, and we may limit attention practically to the second, for silver solder is the most convenient, and will form a good joint with any metals used in the manufacture of present day optical frames, whereas brass is quite unsuitable for gold work, and gold solder is too difficult for the average optician to satisfactorily manipulate. Silver solder is an alloy of various metals, generally composed of two others besides the one which designates it, a useful composition being made from 5 parts of silver, 6 of copper and 2 of zinc.

Some kind of flux is necessary to cause a solder to run over the parts required, and to ensure a clean surface over which it may spread, an important essential in soldering. The apparatus most suitable for melting solder and flux is the jeweller's blowpipe (Chap. XLIV.) used in conjunction with a gas jet, but some arrangement is necessary to keep together the parts to be joined. In certain cases they may be bound round with thin soft iron wire, known as " binding wire," and held by the hand or by pliers, but in other instances a holder or support is useful. Several thicknesses of stout iron wire gauze with a wooden handle underneath may be used, or a slab of asbestos board similarly mounted, upon which the article is placed. Even better is a special holder, devised for gripping the parts and keeping them in juxtaposition.

Fig. 139 is an oblong framework of brass with two loose plates fitting on the ends and held by means of thumb-screws, so that the eyewires may be grasped individually for soldering the joint ends, or both at the same time when the bridge has to be soldered to either of them.

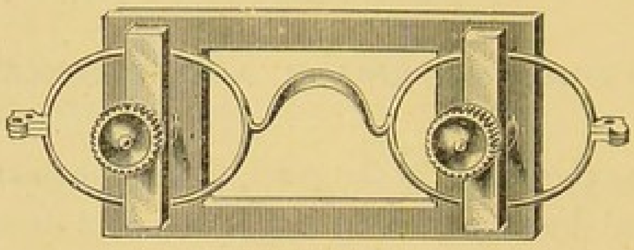


Fig. 139.

Before commencing the actual soldering there are several matters which need attention. The blow-pipe and jet are the most important, for on the skilful manipulation of the flame depends the success in soldering. The air forced into the jet vastly increases its heat, in fact it is a very easy matter to obtain such a temperature as will melt some of the metals of which frames are made, consequently practice in getting a flame of the most useful form is advisable, the blow-pipe illustrated being very convenient. A heavy blast is not suitable, because the flame spreads out into a broad brush like end, with all the noise and disturbance characteristic of heavy blowing, but by the more gentle pressure, which can be obtained by distending the cheeks and breathing steadily through the nose, a *pointed jet* results, and the blast is continuous. This conical flame is illustrated in Fig. 140.

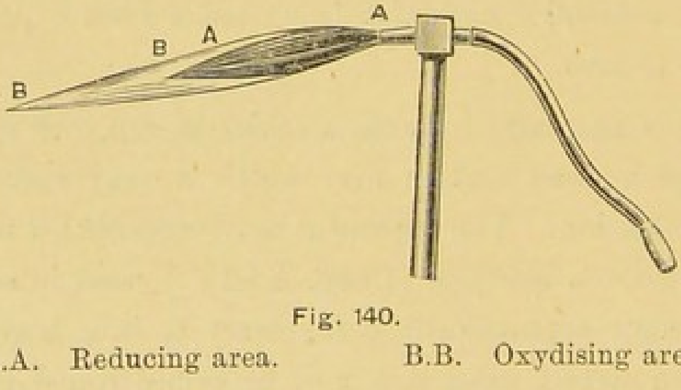


Fig. 140.

A.A. Reducing area. B.B. Oxydising area.

Such a jet may be divided into two portions A.A. and B.B. The first part covers nearly the whole section around the darker inner cone of unburnt gas, which contains a quantity of carbon monoxide at a high temperature. This has a tendency to become carbon dioxide by abstracting oxygen when many oxides are introduced into it. Placed here a piece of glass with much lead in its composition is readily blackened by deposit of the metal from its oxide in the glass. Drawing the same into the region B.B. towards the end of the flame the blackness disappears, due to the reconversion of the metal to its oxide, for here the carbon monoxide is completely burned, being mixed with an excess of oxygen with which the metal unites. These peculiar properties of the two parts of the flame give them the names of "*reducing area*" and "*oxydising area.*" It is in the oxydising area, at a distance of about one-third of its length from the tip of the inner cone, where soldering is done.

It is not only necessary to melt the solder, but the parts to be joined must be simultaneously raised to the same heat. An apparent anomaly confronts us here, for silver solder, being a mixture of silver and copper, (the latter requiring a higher temperature than silver to melt it) would seem to be quite unsuitable for joining silver ware, which would be spoiled by melting, for fusion of parts must never occur. How is this obviated? In any alloy the fusion temperature is actually lower than that of any of its constituents, provided they form a considerable part. Hence silver solder melts at a lower temperature than either silver or copper, and can be used to join any metals with a higher fusion point. For optical purposes the solder should be obtained in thin sheets or strips, and divided into small squares about $\frac{1}{16}$ of an inch across.

The flux employed is usually crystallized borax, a piece of which is rubbed in water upon a hard surface such as slate, forming a very thin creamy paste, a small portion of which is taken up on a fine camel-hair brush and applied to the surfaces. Various ready mixed soldering fluids are sold, and these are clean and easy to manipulate.

Whatever metals have to be soldered it is essential that the solder, flux and parts to be joined are scrupulously clean, and without any suspicion of grease or oil. Oxidation of parts, dirt and impurities in the solder are each and all fatal to a strong union.

In many repairs which are likely to occur the eyewire has broken away at the union with joint or bridge, consequently it has to be fitted back into the groove which it has left. *Not only must the wire be carefully filed or scraped until all the old solder is removed and the bare metal shines, but the corresponding part into which it fits should be similarly treated.* The two are now brought into contact, and fixed so that they cannot move, a small portion of the borax paste being placed *on and above* the junction, and *into this paste* the piece of solder is inserted. These operations apply equally well to steel, gold, or any other metal, but the use of the flame requires great care when silver or gold (especially if this is of low quality) has to be soldered. There is no risk of melting steel, for it needs a higher temperature than the blowpipe used will produce, but it is very different with the more valuable metals, where there is very great danger of fusing the thin eyewires.

The molten solder flows towards and over the hottest parts, so that where the hottest part of the flame is directed, there the solder runs, but this should not tempt the worker to increase the heat much above fusion point. During the whole process of melting, the solder *never rises above its fusion temperature* whatever heat is directed on to it ; but once molten, its heat rapidly increases, and just at this point care is absolutely necessary, for a great rise in temperature will melt the metal.

Screws are better removed from joints before soldering, and may be substituted by a small wooden peg so adjusted as to allow the joints to remain just parted, thus preventing solder from uniting them, or a small piece of paper may be inserted between the parts, which serves the same end when burnt.

A broken folder spring or the curl side of a spectacle cannot be effectively repaired by soldering, for the temper, once destroyed, cannot be renewed when such joining exists.

Some few files are necessary for clearing away superfluous solder after the operation is complete. These may be flat and triangular, but must be finely cut, the triangular tool having a fine tapering point for removing solder from parts difficult of access. A burnisher and some very fine sand-paper completes this part of the outfit. It must be remembered that the amount of solder left outside will be some indication as to how much has run between the joined parts, although so long as a union exists over the whole surface this is all that is necessary, and the less solder used the better the joint, as a rule. Any nickelled steel article is certain to have the deposit of nickel more or less burned, and all that can be done is to carefully *burnish up* the affected parts. Strawed or blued steel frames need most careful cleaning and burnishing to remove every mark and particle of dirt before the joined portion is recoloured. To make this appear like the other adjacent parts is, after soldering, almost impossible, but by quickly passing it through a small amount of sand heated over a spirit or gas flame very good results can with practice be attained. Gold articles cannot so readily be cleaned, and the brownish oxide formed by the flame is best removed by dipping them into heated dilute hydrochloric acid (strength about 1 in 3) in a copper vessel, the operation being technically known as "boiling out," subsequent washing and drying being necessary. This solution must not remain in the copper pan, but be kept in earthenware. The oxide may also be carefully *scraped* away, and the surface well burnished.

Every precaution must be taken that the parts joined are in the correct position, for if a bridge is joined to an eyewire only a trifle out of the right place, the whole will be incorrectly set, or if an eyewire is not inserted into the slot of a joint to the same extent as previously, the lens when screwed in will be loose, and a new one will become necessary.

The methods described are not those adopted in the actual manufacture of steel frames, brass wire being employed in brazing parts together, but as this is not so useful to an optician, who may be called upon to repair many different articles and various metals, the details are omitted.

Gold filled frames may be treated as gold ones in soldering, but must be cleared by *very fine files*, only the smallest amount of solder being used, and great care exercised that the thin gold casing does not fuse.

Where solder runs into the groove of an eyewire a graver or the small toothed wheel may be used to clear it out.

Summary :—

(*a*) It is better to employ silver solder only, both for simplicity and saving of time.

(*b*) A flux must run properly over both the surfaces to be united.

(*c*) Parts to be joined must be rigidly fixed in their required positions.

(*d*) Attention must be paid to the size and shape of the flame used.

(*e*) Care is necessary to avoid overheating, and the consequent fusion of silver, gold and gold filled articles.

CHAPTER LVI.

TYPES OF GOGGLES, PROTECTORS, ETC., AND THEIR USES.

PROTECTORS for the eyes depend as to style and character upon the use for which they are intended. They are made either for cutting off superfluous light from the retina, or for shielding the cornea, conjunctiva or eyelids from injury by wind or flying particles, and in some cases for both these purposes combined. In the first category we find them required for photophobia and inflammatory conditions of the retina, and then they will always be glazed with flat or dome shaped tinted glasses, of shades at present numbered from 1 to 6, the two first being light, the third and fourth medium, and the two last dark tints. For protection of the normal retina, as in metal smelting and in electric light works, deeper tints will be required, in some cases even so intense in colour as to obscure all objects not self luminous or very brightly illuminated.

Under the heading of protectors pure and simple come such kinds as are required by quarrymen, stonebreakers, cyclists, motorists and others exposed to dust or flying particles. For protection from *both light and injury* (except in brilliant sunshine on dusty white roads) they are rarely required in this country, but in some regions where dust-storms are violent, and the glare reflected from rock and earth is unendurable to the white man they are absolutely necessary. In these regions the more heavily pigmented iris and choroid of the eye of the native serve the same purpose as the tint of the protector.

The simplest form merely for protection from injury is the stone-breakers' goggle, two oval cup shaped eye-covers of wire gauze, joined together over the nose by elastic tape, a piece of which also encircles the head to retain the cups in position. Some have white or coloured plano glasses inserted in front, thus avoiding the shadows otherwise cast by the strands of the gauze. They may also be obtained fitted with velvet edges and straight sides, which are then attached to the margins of the wire cups.

Quarry-men require larger eyepieces, and frequently use a spectacle with folding gauze sides, the frame being of the ordinary type. This may be glazed with heavy plano white glass or mica. The latter gives a lighter article, is unbreakable and cooler, but is very detrimental on account of its distortion and irregular refraction, due to waviness and fine lines in the material. Cyclists and drivers also make use of these, either with white or smoked dome glasses, and they should have curl or cable sides, so that they will not slip off the face. The fine network of the cups prevents dust from injuring the eyes, and still allows air to pass through. Mica is not advisable for these, as it is injured by wet.

The modern type of goggle for motorists is usually made with glasses from 2 to 2½ inches long, and of corresponding width. The frames have curl sides, and are jointed at the bridge for folding into small compass. Some have a silk or leather mask attached to protect the cheeks, a space being cut away for the nose, others have merely a full cup round each eye.

The most complete form of protector is the pillar frame goggle, a bar of metal springing from one half of the joint and extending to the top of the gauze cup, where the ordinary side is hinged upon it. The cup is fitted into a heavy eyewire, a secondary eyewire *fitted within this* holding the glass, plano, spherical, or dome shaped as the case may require. It is made in two forms, (1), the "full cup" having margins shaped to fit closely around the eye in every part, or, (2), the "half cup" which slopes from nearly the same height as the full cup at the temporal ends, to the level of the eyewires at the nasal ends, giving complete protection to the outer part of the orbit only, but allowing more air to circulate within the cups.

Pillar frames are made in steel, white metal and gold, the first being of very little use in climates where the air is laden with moisture, and in many of these cases white metal wears well. Occasionally, when required for high northern latitudes, where contact of metal with the bare skin cannot be tolerated, the whole of the sides must be covered with silk or similar material, in addition to the velvet edging round the cups.

Some form of protector already mentioned is now generally used in place of the older D eye or horse-shoe shaped spectacle, which consists of four glasses, two in front, and one at each side folding inwards. The side pieces may contain suitable flat wire gauze instead of glass. They may have either straight, turnpin, curl or cable sides.

A simple form of spectacle glazed with coloured plano or dome shaped glasses is more commonly used than any of these, the greater demand in summer indicating the necessity felt by many persons for some protection from the glare of the sun. Those glazed with dome shaped glasses have the advantage of permitting more air to circulate between the cornea and the protector, and allowing more space for the eyelashes, but from the point of view of the refractionist flat glasses are superior, as when they are "worked" they do not alter parallel light passing through them, but when merely of sheet glass they may be even worse than the dome shaped. These, known also as globular glasses, are either blown glass, or worked in manufacture, the former being always used for the ready made cheap spectacles. Worked glasses are ground by tools, this insuring a correct surface, whereas in the blown article, lines, scratches and irregular curvature cause at times almost every defect which the optician should try to avoid in a lens. Even in the worked glasses, as usually sold, parallelism of the curved surfaces does not secure freedom from refraction, a very slight concave effect being produced.

Tinted glasses have been made in a great variety of colours, but we need only consider those known as blue and London smoke. These tints are obtained by mixing certain minerals with the constituents of the glass, but uniformity cannot be secured even by the most exact mixtures, for although the shades may be of approximately the same density, they partake of different hues which slightly tinge the smoke or blue, due to chemical changes occurring when the glass is in a molten condition. Consequently there is often great difficulty in matching exactly a glass of certain tint, and it is advisable in these cases to substitute a fresh pair of glasses of the same depth of colour rather than to use one which does not correspond in colour with the other.

Tints are usually supplied from a series of 6, distinguished either by letters or figures, the first indicating the lightest. Figures are probably better than letters, inasmuch as the depth of colour can be better defined by addition or subtraction, for Nos. 1 and 2 placed together should give No. 3, and Nos. 2 and 4 similarly should approach the depth of No. 6.

Special purposes require additions to this series, and four deeper tints are generally kept by wholesale houses. For electric light work smoke glasses of even greater density are necessary, and a deep common blue plano of pressed glass, mounted in a German silver frame, is much in demand in iron smelting districts.

In prescribing tinted glasses it is well to remember that smoked glasses do not alter the character of the light which passes through them, but a blue glass before the eye cuts off the orange portion of the spectrum, a part where luminosity is most intense, and consequently where relief from intensity is required they undoubtedly relieve the retina.

There are several features which demand attention in the prescription of tinted glasses, especially if combined with refractive power. They are certain to alter the stimulus of light on the perceptive retinal elements, and will in most cases also affect the size of the pupil, and probably will influence the accommodative power to some slight extent, by reflex action. They should therefore never be used in asthenopia arising from purely refractional causes.

Summary :—

(*a*) Protectors may be used either to shield the eyes from injury or to cut off superfluous light.

(*b*) For complete protection from wind and dust the pillar frame goggle is the best.

(*c*) "Worked" glasses are far superior to common ones.

(*d*) Tinted lenses cannot always be exactly matched in shade.

(*e*) Flat glasses *only* are without refraction.

(*f*) Ordinary asthenopic cases must never be given tinted glasses.

Chapter LVII.

* ARTIFICIAL EYES, MEASUREMENT AND FITTING.

ARTIFICIAL eyes are made of various shapes for different conditions of eye sockets. The simplest and commonest form is merely a shell, and is that found in general use, but far more suitable in many special instances are the improved double walled and bulbous eyes of Snellen, which are vastly superior in general appearance when worn, besides fitting the cavity better, and having a more natural movement communicated to them.

The cavity to which an artificial eye is fitted may be the result of entire removal of the bulb from the optic nerve, or merely a portion from the front may have been excised, leaving a shrunken stump (the sclerotic coat) to which the muscles are still attached. In the first case after healing there will be a larger or smaller flattish pad or stump formed by the recti, and covered with a conjunctival tissue, by which the substitute will be supported. In some rare instances a shell is fitted to hide a deformed or shrivelled natural eye.

To whatever socket artificial eyes are adjusted fitting is of primary importance. They should be exactly centered, of suitable size for permitting slight concomitant orbicular movements, and must always allow the lids to close over them without provoking an excessive amount of secretion.

Inspection of the cavity into which the shell is to be inserted must be made before measurement of the size, consideration of the details of colour, &c. The eyelids may be taken in both hands and drawn carefully outwards, avoiding undue stretching in the process; the operator may then, by rotating his own head, examine the cavity, noting especially the exterior palpebral ligament, which serves to retain the eye shell in position by means of the recess formed in the margin.

Trial with a small eye first is recommended, for then an estimate can be formed of the differences required for a correct fit. In case this falls inwards by reason of the excessive capacity of the orbit it is evident that elongation

* We are indebted to Mr. Pache, of Birmingham, for revising this Chapter.

of the sides of the shell will be necessary in certain directions, or a Snellen's reformed eye may be fitted for trial, always choosing a small one for making the estimation.

No trial should be made while any inflammation is present, and in every case the cavity should be perfectly healthy, smooth, free from all adhesions, discharges or fungosities, and contain a stump of sufficient size and mobility. When a socket is very sensitive and an artificial eye has not been worn, it is sometimes found impossible to fit one until the cavity has been rendered insensitive through the application, by the doctor, of a solution of cocaine. Such an application renders fitting both easy and painless.

After evisceration of an eye an artificial stump is sometimes made by the surgeon, on the principle of Mules. This is done merely to improve the character of the resultant stump, and to give a more natural and lively movement to the artificial eye subsequently fitted. The plan is to enclose in the empty sclerotic coat a hollow glass or silver sphere of suitable size, over which the sclerotic with the muscles attached, and the conjunctiva, are afterwards closed and sewn separately. In cases where the entire globe is removed, the sphere is inserted in the cavity of Tenon's capsule, the muscles and the conjunctiva being closed over it similarly.

In making specifications for an artificial eye it is necessary to note the approximate age of the patient, for in youth the natural organ is of greater curvature on its front surface, and the shell suitable for a child will approach the spherical in form, and possess a more centrally placed pupil.

Irritation through roughness of the artificial eye or from projections in the cavity pressing against it must be specially avoided. The acme of fitting is attained when the client himself is unconscious of the presence of the eye in the socket.

It is very necessary to note for which orbit the eye is required, because, as will be seen from Fig. 141, the pupil is nearer the inner canthus than the outer one, and artificial eyes are made as "rights" and "lefts" accordingly. It should be noticed that the broad part of an artificial eye is the outer or temporal end, the narrower and more pointed extremity being made to fit the inner canthus, whilst the notched or indented portion on the edge of the shell is an indication of the *upper* margin, and is necessary on account of the anatomical formation of the corresponding portion of the socket.

The illustration shows the method of measurement employed in taking length, breadth and depth, these being best expressed in millimetres, for accuracy. In addition, it is most essential that a sketch of the eye be made, if possible in both positions shown, and only by such can hollows or notches be indicated on the margins with exactness. For those wearing an eye for the first time a slightly smaller one is much better than what might be described as exactly the right size, as the movement will be brisker, and it will not seem so conspicuous.

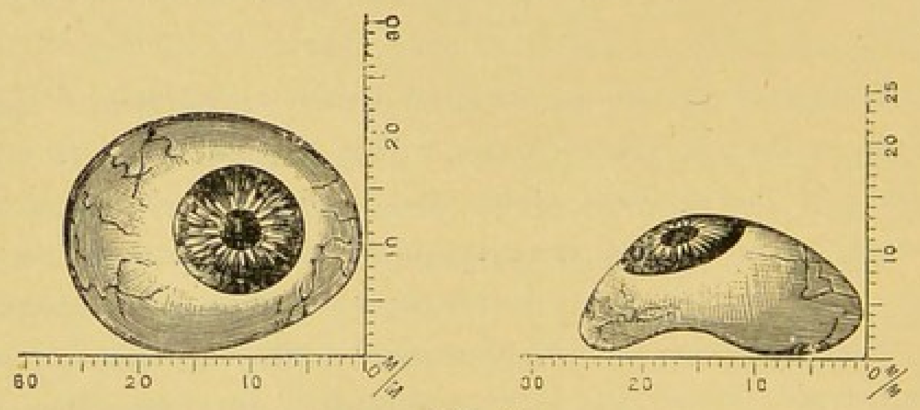


Fig 141.

When ordering a *special* it should be stated whether the eyeball has been entirely removed or a useful stump remains, also whether the sound eye is full and prominent or small and sunken. Occasionally a wax composition model may be made with advantage, especially in the case of a contracted orbit, and when ridges and furrows exist it is essential for obtaining the special shape.

The iris and pupil must be carefully measured for diameters in millimetres, and attention devoted to the colour and markings in the iris of the sound eye. Both these vary so much that quite a large assortment of shades may not provide an exact match. For those acquainted with the methods of mixing water colours the difficulty of matching tints may, with a little practice, be overcome, lighter and darker parts being indicated in a coloured sketch.

The white portion, or sclerotic, cannot perhaps so readily be represented with fidelity to nature, but some attempt may always be made at marking blood vessels when characteristic and very noticeable, the sclerotic ground being described as bluish white, clear white, yellowish white, brownish white, etc.

Where an artificial eye has been worn previously without satisfaction, any alterations required must be carefully noted, whether of form or colour, and any uneasiness or discomfort must be remedied by an appropriate alteration in contour of the part causing trouble, either at the margin or hollowed portion.

It is a good plan in these instances for a large full faced photograph to be taken of the client with the old eye in position. This should be forwarded along with the old eye to the maker, who is often enabled to remedy many defects of fitting from the appearance presented.

For inserting and removing the eye we cannot do better than quote the instructions given to the patients at Moorfields Hospital ; "To put the eye in :—Place the left hand flat on the forehead, and with the two middle fingers raise the upper eyelid towards the eyebrow ; then, with the right hand push the upper edge of the artificial eye beneath the upper lid, which may be allowed to drop upon the eye. The eye must then be supported with the middle fingers of the left hand, whilst the lower eyelid is raised over its lower edge with the right hand."

"To take the eye out :—The lower lid must be drawn downward with the middle finger of the left hand ; and then, with the right hand, the end of a small bodkin must be put beneath the lower edge of the artificial eye, which must be raised gently forward over the lower eyelid, when it will drop out readily. At this time care must be taken that the eye does not fall on the ground or other hard place, as it is very brittle, and may easily be broken by a fall."

An eye of large size may be more readily inserted by the wearer looking downwards, while one smaller is better put in during an upward look.

Owing to the continual motion of an artificial eye in the saline orbital fluid, and the friction of the lids it loses its smooth surface and acquires a rough one in about twelve months' time, necessitating re-enamelling or renewal. If wear is persisted in after excessive roughness is developed there is danger of exciting inflammation in the socket.

All new eyes must be carefully examined for roughness of edges or hollows ; they should be perfectly smooth, well polished on both surfaces, and thoroughly well annealed.

Before use, after handling, and after any trial they must always be sterilized in solution of carbolic acid, 1 part to 120 of water, to ensure safety ; in fact it is necessary to take every precaution to keep them in perfectly aseptic condition.

Artificial eyes should be removed from the cavity every night at bed time, and are better placed in a solution of boric acid (1 part to 30 of water), which, if warmed to about blood heat, lessens their liability to fracture by the sudden change of temperature. This liability only occurs in the commoner articles ; well made eyes will not be affected by such changes.

Cheap foreign eyes are frequently badly annealed, and with change of temperature are very prone to fracture at the junction of the iris with the sclerotic, where the thicker portion of the material unites with the thinner, the unequal contraction or expansion of the parts, with varying temperatures, being the *primary* cause.

It is also advisable for the wearer to cleanse the orbital cavity night and morning with a *weak* tepid solution of the same antiseptic, which may be applied by means of an eye cup, the head being thrown back to allow contact of the liquid for a minute or two.

It is seldom possible to fit an artificial eye with any real approach to satisfaction for at least a month after an operation, six weeks or two months being a more suitable period to allow, whenever it is convenient to the client to wait so long.

In selecting eyes from stock the first thing to notice is whether "right" or "left" is required, next the colour and size of the iris and the diameter of the pupil, together with the tint of the sclerotic are observed, then a selection of eyes is *tried successively in the socket*, until one is obtained which is either satisfactory, or is capable of affording satisfactory data for the making of a special. The smaller eyes of the selection are tried first, followed by the next larger ones in succession, as long as is found necessary.

Summary:—

(*a*) Correct fitting is of primary importance.

(*b*) The eyelids must close easily over the artificial eye.

(*c*) The cavity must be carefully inspected before even a small eye is tried.

(*d*) The youthful age of a wearer influences the curvature.

(*e*) A rather smaller eye moves better in the orbit.

(*f*) Measurements of pupil and iris, length from canthus to canthus, and width are essential.

(*g*) All artificial eyes should be well polished, and not have any rough places.

(*h*) Cavity and shell should be kept well cleansed and aseptic.

Chapter LVIII.

MODEL, AMBIGUOUS AND OBSCURE PRESCRIPTIONS.

A PRESCRIPTION represents the final result obtained from sight testing, frame fitting and record making. So far as the frame is concerned it agrees exactly with the record book, but that part referring to the refractive correction required is the essence of the many facts and data obtained during the tests.

There are thus two parts of a prescription, the first dealing solely with the lenses, and the second with the measurements, etc., required for a frame to hold these. On the next page is shown a model prescription, in which all the details necessary for obtaining an accurate fit of frame and a precise adjustment of lenses are shown.

The chief features to note in giving details of lenses are the correct use of plus and minus signs before the powers. It is generally understood that a power written without a sign, as in algebra, signifies a plus, or convex lens, but such a procedure is as dangerous as it is troublesome.

The *spherical power* should always be written first, accompanied by "Sph.," "Sp.," or "S.," following the D indicating the use of the dioptric system. When no cylindrical lens is used in combination with it, the specification "Sph." may be omitted. Many oculists and opticians make a rule of omitting these letters altogether, simply trusting to the universal usage of the English speaking nations; this is to be deprecated, not so much on the ground of want of preciseness as risk of error occurring in making up such a prescription if the client should happen to be in France or some other foreign country, and accidentally to lose or destroy his spectacle.

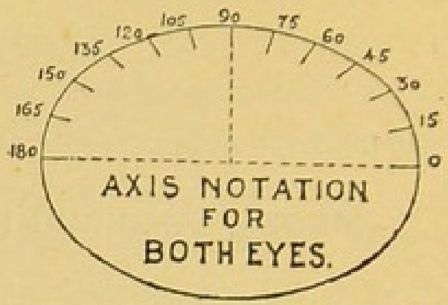
Next to the spherical power the cylinder (if any) must be indicated, the *sign* being distinctly marked and the letters "Cyl." added, the abbreviations "Cy." and "C." appearing here occasionally. To show that the cylinder is combined with the spherical the sign ⌓⌣ (meaning *combined with*) is generally used. In many oculists' prescriptions the letter c., $\bar{c}$., or the word "*cum*" is used, all being Latin forms, with the same meaning as the sign referred to.

LENSES.

Distance { O.D. ....
 O.S. ....

Reading { O.D. ....
 O.S. ....

Remarks ....



Spectacles.

FRAMES.

No. of Frame } or Pattern } .... Material ....

Centres (Distance) .... (Reading) ....

Front .... Shape and size of eye ....

Bridge. Height (Distance) .... (Reading) ....

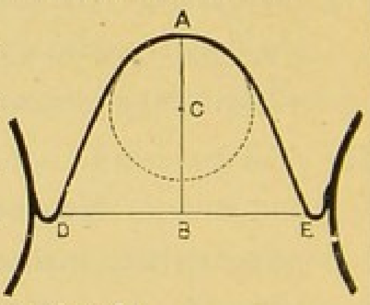
Projection (Distance) .... (Reading) ....

Width of base (DE.) ....

Depth (AB.) ....

Radius of apical circle (AC.) ....

Angle of crest with eyewires ....



Sides. Straight (length) ....

Curl (total length) .... (length to bend) ....

Cable (total length) .... (length to bend) ....

Remarks ....

....

....

Eye-Glasses. No. of Frame } or Pattern } .... Material ....

Shape and size of eye ......

Plaquets .... Angle of same ....

Width apart at top .... Width at bottom ....

Offset .... Rake to eyewires ....

Handle ....

Catch ....

Remarks ....

....

....

Date ....

Record No. .... Signature ....

Not infrequently another method of arrangement is resorted to, the spherical power being written above the cylindrical, with a line dividing them, as $\frac{+4\text{D Sph}}{+1{\cdot}25\text{D Cyl}}$ or even $\frac{+4\text{D}}{+1{\cdot}25\text{D}}$, the desire for brevity at the expense of careful method leading some even to abandon the D.

Upon the ordinary type of printed prescription form all that we have already noted may be written in at least two, and possibly four places. Due note must therefore be taken to see whether the figures are placed opposite O.D. (oculus dexter), in English, right eye (R.E.), or after O.S. (oculus sinister) meaning left eye (L.E.), a further error being possible between the "reading" and "distance" spaces. A mistake here may lead to considerable trouble, as in the one case the lenses may be before the wrong eyes, and in the other may actually be placed in the wrong frames.

So far no mention has been made of the marking of the axis of a cylinder on the prescription, a matter calling for the greatest care. In Chap. XLVI. reference was made to the "Standard Notation," in which it is merely necessary to specify any required degree of the protractor to convey exact information *for either eye*, so that no confusion can arise. If this system is followed out, the number referred to is best written immediately after the cylinder prescribed.

In most French prescriptions all this is reversed, the axis of the cylinder coming first, next the cylindrical power, and finally the spherical. The distinguishing letters after the powers are often conspicuous by their absence.

Should a prism be required, it must be clearly marked with respect to method of measurement, either in degrees of inclination (refracting angle), written °, in degrees of deviation written °d, or in prism dioptres written $^{\Delta}$, and the position of the base specified according to the marks of a protractor of the standard notation, unless, as is more usual, the base is described as either "in," "out," "up," or "down," oblique positions being comparatively rare.

Cylindrical axis notation is often a source of trouble, unless the translator of a ℞ understands the particular system used by the compiler. The system generally in use before the standard notation was introduced agreed with that form for the left eye *only*, the right counting 0° from the outside, working round to 180° at the nose, so that R.E. counted with the movement of the hands of a watch, and L.E. against. This necessitated some distinctive mark, showing the actual axis position, and unfortunately retention of this method in use is frequently the cause of errors.

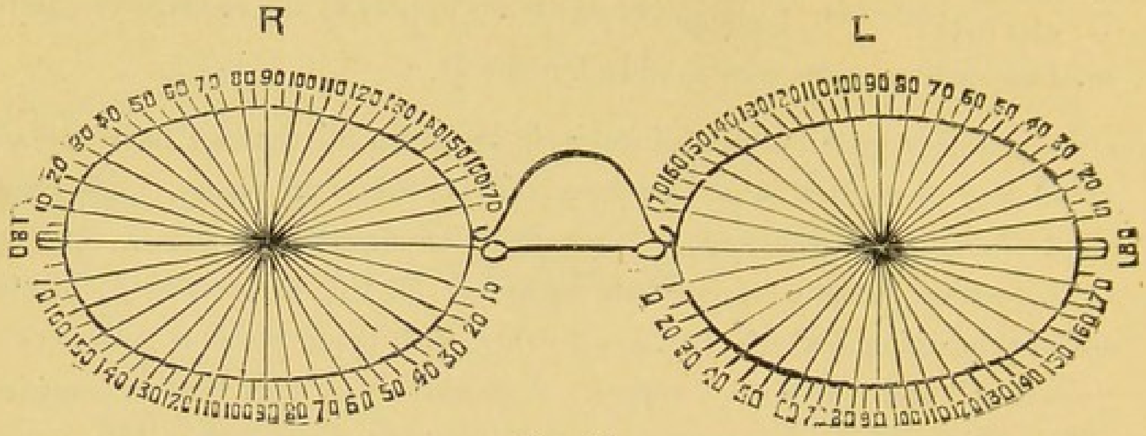


Fig. 142.
Old Notation.

One way of overcoming the difficulty has been adopted by many medical men, who use N and T for nasal and temporal, the vertical line of the protractor being denoted by V and the horizontal by H, the degrees then running both ways from 0° at V to 90° at H. When the *eye is specified* no confusion can possibly result, but still as a system of notation it is inferior to the standard. The presence of letters d.c.v. or d.c.h. after a lens are a consequence of the use of the N. and T., the full meaning being " D. cyl. axis vertical " or " D. cyl. axis horizontal " respectively.

With the same form of notation a very rare reading is that in which one scale serves for both eyes, the right upper half being denoted + and the left upper —. It can only be a source of confusion, and has no really good points.

Occasionally the expressions " down and in " and " down and out " are used to denote the axis direction, the zero being horizontal. In few methods is ambiguity more likely to be troublesome, unless the system is illustrated by a diagram.

Lenses ordered from tests made with the stenopaic slit or by retinoscopy may not always be found written in their simplest form, but may remain in the ℞ as crossed cyls. The axes in degrees attached to each (being at right angles), should indicate this, but occasionally obscurity is introduced by the presence of a figure L, although the two axes may really be at 135° and 45°, the intention being to thereby accentuate the *relative* positions without indicating their real ones.

Prescriptions direct from hospitals are almost always records also, and rarely contain any details for frame measurements. In some of these, when the optician is quite unacquainted with the customs and uses obtaining at the institution, considerable circumspection is called for. The record, complete in itself, may seem very indefinite to anyone unused to such, and occasionally does not even indicate the exact lenses which should be fitted, the expression " under atropine " or merely " atrop." leaving it doubtful whether the usual necessary allowance required on account of the influence of the drug, has been made.

Summary :—

(*a*) + and − signs should always be used, but " sph." may be omitted when a spherical alone is required.

(*b*) The order of writing lens formulæ should always be (1) sph. (2) cyl. (3) prism.

(*c*) The standard notation is the only method by which figures alone will express the axis for both eyes without ambiguity.

(*d*) Where a prescription seems ambiguous or incomplete, and a lens has been previously supplied, then the o'd lens, or even a part of it should be carefully examined.

Symbols and Abbreviations with their Alternatives and Meanings employed by various authors.

A. Ac. Acc.	...	Accommodation.
A^c ...	...	Relative Range of Convergence.
Æt. Æ....	...	Aged.
Ah. ...	...	Hyperopic Astigmatism.
Ahm. Amh.	...	Mixed Astigmatism.
Am. ...	...	Ametropia. Ametropic.
A.m. ...	...	Myopic Astigmatism.
An. ...	...	Anisometropia.
As. ...	...	Astigmatism. Astigmatic.
As. H. ...	...	Hyperopic Astigmatism.
As. M. ...	...	Myopic Astigmatism.
Asym. ...	...	Asymmetric.
Ax. ...	...	Axis.
B ...	...	Base of Bridge.
B E ...	...	Both Eyes. The eyes together.
B D ...	...	Base (of prism) down.
B I ...	...	,, ,, in.
B O ...	...	,, ,, out.
B U ...	...	,, ,, up.
C ...	...	Cylinder. Cylindrical. Convergence.
c. ...	...	Cum. With.
C^a ...	...	Relative range of accommodation.
Cc. ...	...	Concave. (Minus, or —).
cm. ...	...	Centimetre.
Con. ...	...	Convergence.
Crys. ...	...	Crystalline lens.
Cve. ...	...	Concave. Minus.
Cvx. ...	...	Convex. Plus.
Cx. ...	...	Convex. (Plus, or +).
Cyl. ...	...	Cylinder. Cylindrical.
D. ...	...	Dioptre.

Dcc. ...	... Double Concave.
Dcx. ...	... Double Convex.
E. Em. ...	... Emmetropia. Emmetropic.
—e.e. ...	... Minus every letter. None seen on the card.
F ...	... Formula. Focal power of lens or mirror.
f ...	... Focal length.
FP. ...	... Farpoint (punctum remotum).
FV. F.O.V.	... Field of Vision.
H ...	... Hyperopia. Hyperopic. Horizontal.
H ...	... Height of bridge.
Hl ...	... Hyperopia latent.
Hm. ...	... Hyperopia manifest.
Ht. ...	... Hyperopia total.
Hy. ...	... Hyperopia. Hyperopic.
H. As ...	... Hyperopic Astigmatism.
In. ...	... Inch. ″
J ...	... Jaeger.
L ...	... Left.
L D ...	... Light difference.
L E ...	... Left eye (oculus sinister)
L M ...	... Light-minimum.
M ...	... Myopia. Myopic.
m ...	... metre.
Mer. ...	... Meridian.
M A ...	... Meter Angle.
M As ...	... Myopic Astigmatism.
mm. ...	... Millimetre.
My. ...	... Myopia. Myopic.
n ...	... Nasal.
NA ...	... Numerical aperture.
NP ...	... Nearpoint. Punctum proximum.
O ...	... Oculus. The eye.
O_2 ...	... Both eyes.
OD ...	... Right eye.
ODV ...	... Vision of Right eye.
OS ...	... Left eye.
OSV ...	... Vision of Left eye.

OV	Both eyes.
P. Pb. Pr.	Presbyopia. Presbyopic.
P.	Projection of bridge.
P. or P.P.	Punctum Proximum. Nearpoint.
p. or pp.	Ditto.
P^a	Nearpoint of accommodation.
P^c	Nearpoint of convergence.
Pc	Periscopic.
Pcc	Periscopic concave.
Pcx	Periscopic convex.
Pr	Prism.
P D	Pupillary (or interpupillary) distance.
P.D.	Prism dioptre.
PL	Perception of Light.
P R or pr.	Punctum Remotum. Farpoint.
R	Right.
r	Radius of curvature. Punctum remotum (farpoint).
R^a	Farpoint of accommodation.
R^c	Farpoint of convergence.
R E	Right eye (Oculus dexter).
R T	Reading test.
S	Sight. Snellen.
Sb	Strabismus.
S. Sph.	Spherical. Spherical lens.
Sym.	Symmetric.
T.	Temporal.
T.	Tension of eyeball.
U	Curvature of incident wave.
V	Curvature of reflected or refracted wave.
V	Visus. Vision. Visual acuity. Vertical.
V^D	Velocity.
V A	Visual acuity.
w	With.
α	Refracting angle.
YS.	Yellow spot.
δ	Angle of deviation.
λ	Wave length.

n μ	... ...	Refractive Index.
μ	... ...	1 micron $\left(\frac{1}{1000}\text{ mm.}\right)$
°	... ...	Degree.
′	... ...	Minute. Foot.
″	... ...	Second. Inch.
‴	... ...	Line.
△	... ...	Prism Dioptre. Index of dispersion.
△	... ...	Mean dispersion $(n_F - n_C)$
+	... ...	Plus. Convex. Positive.
—	... ...	Minus. Concave. Negative.
=	... ...	Equal to.
>	... ...	Greater than.
<	... ...	Less than.
∟	... ...	At right angles to.
⊥	... ...	Perpendicular to.
∥	... ...	Parallel to.
◯	... ...	Combined with.
∞	... ...	Infinity (practically 20 ft. or 6 m.)
℞	... ...	Recipe. Prescription.

The Optical Society's Standards.

(Extract).

METRIC SYSTEM.—That the Metric System be used for all linear measurements of frame or face, and that angular measurements be expressed by degrees.

SIZES OF EYES.—That standard sizes of eyes be based on the peripheral measurement of the lenses or eye plates, and that the following would be a suitable series: Size No. 1 having a peripheral measurement of 92·5 millimetres, and each following size being larger than the size immediately preceding it by a number of millimetres equal to its own number in the series, viz.:—

		Length of Periphery.				
No. 1	—	92·5 m/m	...	...	(American, No. 4)
No. 2	—	94·5 ,,	92·5+2	...	(American, No. 3)
No. 3	—	97·5 ,,	94·5+3	...	(American, No. 2)
No. 4	—	101·5 ,,	97·5+4	...	(American, No. 1)
No. 5	—	106·5 ,,	101·5+5	...	(American, No. 0)
No. 6	—	112·5 ,,	106·5+6	...	(American, No. 00)

This numeration to be applied, on the same basis of measurement, to all shapes of eyes.

The recognised shapes of eyes are:—Round, Oval, Long Oval, Round Oval, Pantoscopic, Half Oval.

It is recommended that the sizes and shapes of ovals and long oval eyeplates be defined by the given values of the periphery and of the long axis, and that the sizes of round eye plates be defined by given values of the circumference and of the diameter; the diameter of round plates and the long axis of other shapes being as follows:—

No.	Round.	Oval.	Long Oval.	Round Oval.	Pantoscopic.	Half Oval.
1.	29·5	33·5	35	31	34	36 m/m
2.	30	34	35·5	31·5	34·5	36·5 ,,
3.	31	35	36·5	32·5	35·5	37·5 ,,
4.	32·5	36·5	38	34	37	— ,,
5.	34	38	39·5	35·5	38·5	— ,,
6.	36	40	41·5	37·5	40·5	— ,,

The ratio of the two axes being: in the oval, 4 to 3 (approx.); and in the long oval, 3 to 2 (approx.).

WIDTH OF EYEWIRES.—That standard widths of eyewires be based on the Imperial Wire Gauge, as follows :—

No. 20	is	the	wire	hitherto	known	as	6/-	wire.
,, 19	,,	,,	,,	,,	,,	,,	4/-	,,
,, 18	,,	,,	,,	,,	,,	,,	3/-	,,
,, 17	,,	,,	,,	,,	,,	,,	2/6	,,
,, 16	,,	,,	,,	,,	,,	,,	2/-	,,

METHODS OF MEASUREMENT—(SPECTACLES).

(1). *Bridges.*—(*a*) That the height of a bridge be measured from a horizontal line bisecting the joints to the centre of the bearing surface of the bridge ; the position above the horizontal line to be expressed in millimetres ; the position below to be expressed in millimetres with a minus sign prefixed.

(*b*) That the projection of a bridge be measured from the plane of the back of the eyewires to the centre of the bearing surface of the bridge ; the position outward to be expressed in millimetres ; the position inward to be expressed in millimetres with a minus sign prefixed.

(*c*) That the distance between the lowest points of contact with the nose be the measurement of the base of the bridge of a spectacle frame.

(2). *Fronts.*—That the length of the front of a spectacle frame be the distance from centre to centre of the pins.

Spreads of Bridges (*Spectacles*).—That standard spreads of bridges of spectacles be segments of a curve, 1 centimetre in depth, measured across at distances of 2 and 7 mm. from the apex of the curve. The spreads to be numbered from 1 to 6 ; No. 1 being the narrowest, and its chords to measure 6 and 9 mm. at the upper and lower distances respectively. The other spreads to increase in width progressively by 1·5 mm. at the upper, and 3 mm. at the lower chord. The dimensions of the standard spreads would thus be as follows :—

No. 1	Upper Chord 6 mm.	Lower Chord 9 mm.
2	... 7·5 ,,	... 12 ,,
3	... 9 ,,	... 15 ,,
4	... 10·5 ,,	... 18 ,,
5	... 12 ,,	... 21 ,,
6	... 13·5 ,,	... 24 ,,

Inclination of Bridges (Spectacles).—That the angle of inclination of a spectacle bridge be expressed as so many degrees from the plane of the eyes.

Sides.—(*a*) That the length of a straight side be measured from the inside of the joint to the end of the side when flattened on the rule.

(*b*) That the curve of a side be measured by the length of the sagitta.

(*c*) That the angle of a side be expressed by the number of degrees included by the side and the plane of the eyes.

(*d*) That the dimensions of a curl side be expressed by two measurements, viz. :—

1. The perpendicular distance from the inside of the joint to a straight line tangent to the apex of the curve.

2. The full length be measured in the same manner as a straight side.

Methods of Measurement.—Eyeglasses.

Bridges.—That the inside distance between the extreme points, measured horizontally, be the length of the bridge of an eyeglass frame.

Plaquets.—That it is desirable to record the inclination and distance apart of plaquets by means of a scale consisting of a central vertical line with other vertical lines on either side numbered in millimetres. With straight plaquets the measurements to be taken at the top and bottom ; with curved plaquets at top, centre and bottom ; with rocking plaquets at the centre only. The length of plaquets should also be recorded. For non-symmetrical plaquets the distance from the centre should be noted for each placquet separately. These measurements to be taken while the frame is at rest and not while in use.

Nomenclature—General.

Generic Terms.—That the following be adopted standard generic terms :—Spectacles, Eyeglasses, Single Eyeglass.

Names of Eyes.—That the following be the standard terms denoting various shapes of eyes :—Round, Oval, Long Oval, Round Oval, Pantoscopic, Half Oval.

Nomenclature—Spectacles.

Parts of Spectacles.—That the following be the standard names of various parts of spectacles :—Frame, Lens, Eye, Side, Bridge, Joint, Front, Pin, Screw.

Eyewires.—That the following be the standard terms applied to eyewires :—Grooved wire (for bevelled lens) ; Solid wire (for a grooved lens).

Names of Sides.—That the following be the standard names for spectacle sides :—Straight, Plain Curl, Twisted Curl, Half Curl, Turnpin.

Names of Bridges.—That the following be the standard names of spectacle bridges :—Crank (or C.), Saddle (or W.), Arch (or U.), K., X.

Wire for Bridges.—That the following be the standard terms denoting forms of wire for spectacle bridges :—Narrow wire, Broad wire.

Nomenclature—Eyeglasses.

Classes of Eyeglasses.—That the following be the standard descriptions of eyeglasses :—Folding, Non-folding, Lorgnette.

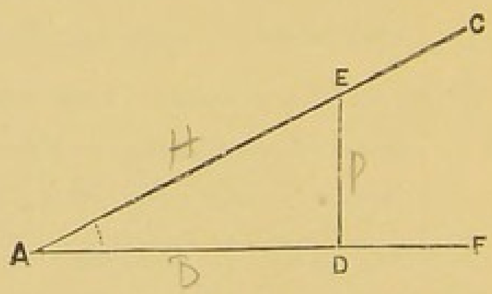
Parts of Eyeglasses.—That the following be the standard names of various parts of eyeglasses :—Frame, Eye, Lens, Bridge, Plaquet, Handle, Joint, Screw, Stud, Spur, Stop, Catch.

Screws.—That the following be the standard sizes of screws and in accordance with those of the British Association :—Nos. 9 and 16 are recommended as the most suitable for spectacle and eyeglass work.

Useful Tables and Data.

Section I.

TABLE I.—The Trigonometrical Ratios.



Let F A C be any angle. From any point in either F A or C A a line can be drawn perpendicular to the other. Let E be chosen in A C, and a perpendicular drawn to F A. Then the angle A D E is a right angle and A D is called the *base*, D E the *perpendicular*, and A E (the side opposite the right angle) the *hypotenuse*. We will denote these by B P and H respectively.

Then $\frac{P}{H}$ is called the *sine* of the angle at A.

,, $\frac{B}{H}$,, *cosine* ,,

,, $\frac{P}{B}$,, *tangent* ,,

,, $\frac{B}{P}$,, *cotangent* ,,

,, $\frac{H}{B}$,, *secant* ,,

,, $\frac{H}{P}$,, *cosecant* ,,

TABLE II.—Trigonometrical Values.

Angle		Chord.	Sine.	Tangent.	Co-tangent.	Cosine.			
De-grees	Radians								
0°	0	0	0	0	∞	1	1·414	1·5708	90°
1	·0175	·017	·0175	·0175	57·2900	·9998	1·402	1·5533	89
2	·0349	·035	·0349	·0349	28·6363	·9994	1·389	1·5359	88
3	·0524	·052	·0523	·0524	19·0811	·9986	1·377	1·5184	87
4	·0698	·070	·0698	·0699	14·3007	·9976	1·364	1·5010	86
5	·0873	·087	·0872	·0875	11·4301	·9962	1·351	1·4835	85
6	·1047	·105	·1045	·1051	9·5144	·9945	1·338	1·4661	84
7	·1222	·122	·1219	·1228	8·1443	·9925	1·325	1·4486	83
8	·1396	·140	·1392	·1405	7·1154	·9903	1·312	1·4312	82
9	·1571	·157	·1564	·1584	6·3138	·9877	1·299	1·4137	81
10	·1745	·174	·1736	·1763	5·6713	·9848	1·286	1·3963	80
11	·1920	·192	·1908	·1944	5·1446	·9816	1·272	1·3788	79
12	·2094	·209	·2079	·2126	4·7046	·9781	1·259	1·3614	78
13	·2269	·226	·2250	·2309	4·3315	·9744	1·245	1·3439	77
14	·2443	·244	·2419	·2493	4·0108	·9703	1·231	1·3265	76
15	·2618	·261	·2588	·2679	3·7321	·9659	1·218	1·3090	75
16	·2793	·278	·2756	·2867	3·4874	·9613	1·204	1·2915	74
17	·2967	·296	·2924	·3057	3·2709	·9563	1·190	1·2741	73
18	·3142	·313	·3090	·3249	3·0777	·9511	1·176	1·2566	72
19	·3316	·330	·3256	·3443	2·9042	·9455	1·161	1·2392	71
20	·3491	·347	·3420	·3640	2·7475	·9397	1·147	1·2217	70
21	·3665	·364	·3584	·3839	2·6051	·9336	1·133	1·2043	69
22	·3840	·382	·3746	·4040	2·4751	·9272	1·118	1·1868	68
23	·4014	·399	·3907	·4245	2·3559	·9205	1·104	1·1694	67
24	·4189	·416	·4067	·4452	2·2460	·9135	1·089	1·1519	66
25	·4363	·433	·4226	·4663	2·1445	·9063	1·075	1·1345	65
26	·4538	·450	·4384	·4877	2·0503	·8988	1·060	1·1170	64
27	·4712	·467	·4540	·5095	1·9626	·8910	1·045	1·0996	63
28	·4887	·484	·4695	·5317	1·8807	·8829	1·030	1·0821	62
29	·5061	·501	·4848	·5543	1·8040	·8746	1·015	1·0647	61
30	·5236	·518	·5000	·5774	1·7321	·8660	1·000	1·0472	60
31	·5411	·534	·5150	·6009	1·6643	·8572	·985	1·0297	59
32	·5585	·551	·5299	·6249	1·6003	·8480	·970	1·0123	58
33	·5760	·568	·5446	·6494	1·5399	·8387	·954	·9948	57
34	·5934	·585	·5592	·6745	1·4826	·8290	·939	·9774	56
35	·6109	·601	·5736	·7002	1·4281	·8192	·923	·9599	55
36	·6283	·618	·5878	·7265	1·3764	·8090	·908	·9425	54
37	·6458	·635	·6018	·7536	1·3270	·7986	·892	·9250	53
38	·6632	·651	·6157	·7813	1·2799	·7880	·877	·9076	52
39	·6807	·668	·6293	·8098	1·2349	·7771	·861	·8901	51
40	·6981	·684	·6428	·8391	1·1918	·7660	·845	·8727	50
41	·7156	·700	·6561	·8693	1·1504	·7547	·829	·8552	49
42	·7330	·717	·6691	·9004	1·1106	·7431	·813	·8378	48
43	·7505	·733	·6820	·9325	1·0724	·7314	·797	·8203	47
44	·7679	·749	·6947	·9657	1·0355	·7193	·781	·8029	46
45°	·7854	·765	·7071	1·0000	1·0000	·7071	·765	·7854	45°
			Cosine	Co-tangent	Tangent	Sine	Chord	Radians	Degrees
								Angle	

TABLE III.—Refractive Indices, &c., of Optical Materials for D line.

	Soft Crown Glass.	Hard Crown Glass.	Light Flint Glass.	Densest Flint Glass.	Canada Balsam.	Water.	Quartz (ordinary ray).	Quartz (extra-ordinary ray).
Refractive Index (n)	1·515	1·517	1·547	1·713	1·526	1·333	1·544	1·553
Medium Dispersion	0·009	0·008	0·011	0·024	0·023	—	0·007	0·008

The Slide Rule.

Parts.—Rule, slide and cursor.

1st Scale of Rule (top part from left 1 to middle 1)
1st Scale of Slide (ditto ditto)

Representations.—The 1st scale is taken as a unit of measure, and the spaces 1—2, 1—3, 1—4, etc., are proportional to the logs of 2. 3, 4, etc., to 10, which last has unity for its logarithm. The spaces 1—2, 2—3, etc., are also divided in the same manner, giving, for example, between 2 and 3 the logs of such numbers as 2·1, 2·3, etc. The lower scale of rule and of slide are alike, and just double the length of the top scales.

Multiplication.—Use the two lower scales of the rule and slide. Make a 1 of the slide coincide with one of the factors which must be read off on the rule scale ; and the product will be found on the scale of the rule opposite to the other factor read on the slide.

Number of figures in Product may be determined either by

(1) The characteristic of the log.

(2) By adding the two factors if the right hand 1 is used, or if the left hand 1 is used by subtracting 1 from the sum of the two factors.

Division.—Use the two lower scales of rule and slide. Place the divisor read on the slide above the dividend read on the rule ; the quotient will be found on the rule below a 1 of the slide.

Number of figures in quotient may be determined by

(1) Deducting the figures in the divisor from those in the dividend if the right hand 1 of the slide points out the answer, and

(2) By deducting the figures in the divisor from those in the dividend and adding one if the left hand 1 of the slide points out the answer.

Proportion.—Perform the necessary operation for finding the *quotient*, and, without reading it, look for the product of this quotient by reading off the third factor on the slide and noting the answer on the rule.

Or use the following rule :—Put the proportion into the form of 2 equal ratios, for instance let $\frac{2}{3} = \frac{4}{x}$ then place 2 over 3 and under 4 on slide read x on rule.

Squares and Square Roots.—The numbers on the upper scales of the rule are the squares of the numbers on the lower scale. Hence, to obtain the square or the square root of a number it is merely requisite to read the numbers opposite to each other, either by the help of the cursor, or by the end marks 1 on the slide.

Note.—In taking the square root of a number the *left* hand top scale must be used if the number has an *odd* number of figures, and the *right* hand top scale if the number has an *even* number of figures.

Cubes of Numbers.—This may be done either by

(1) Setting the 1 on the lower scale of the slide against the number to be cubed on the lower scale of the rule, when over the number on the first scale of the slide will be found the required cube ; or by

(2) Inverting the slide, keeping the same face upwards, and now (using the lower scale of rule and what was formerly the *1st scale* of slide) setting opposite each other the marks which indicate on each scale the number of which the cube is required ; this cube will now be found on the upper scale of the rule opposite to the 1 of the slide (now on the right hand).

CUBE ROOTS.—To find the cube root of a number place (having inverted the slide, keeping the same face up) the now right hand 1 of the slide against the number and seek for a number on the lower scale of the rule which is opposite to the same number on the (now) lower scale of the slide. This number is the cube root required.

Note.—The number of figures in the answer is of course 1 for every 3 (and 1 for the remainder over the even threes, if there is one) in the number whose cube root is to be extracted.

SINES AND TANGENTS.—On the reverse side of the slide will be found the sine and tangent scales marked *S.* and *T.* respectively. Both scales are divided so that the spaces, reckoned from the left of the scales, to 1, 2, 3, etc., represent the logs of the natural sines and tangents of angles of 1°, 2°, 3°, etc., in a circumference whose radius is 100.

The scale required for use is placed into contact with the upper scale of the rule, the sines and tangents can then be read off this scale direct for the various angles.

Note.—Values of the tangents of angles greater than 45° may be obtained by dividing 1 by the tangent of the complementary angle.

To multiply say 38 by sin 15° *direct*, place one extremity of the sine scale against 38, the product will then be found on the scale of the rule opposite to the mark corresponding to sin 15°. (Likewise Tangents).

LOGARITHMS.—On the reverse side of the slide and in the centre is a scale divided into equal parts, and adapted to measure the spaces on the lower scale of the rule which represent the decimal parts of the logarithms of numbers.

To find the log of a number the slide is left in its usual position and the left hand (1) put against the number (on the lower scale of the rule) for which the log is required ; the log of the number will now be found on the scale of equal parts opposite to the mark in the opening at the back of the *right* extremity of the rule. Example, for log 2 we find 301, which must be read as 0·301.

Section II.

TABLE IV.—Measurements of the Eye. (*Jaeger.*)

Antero-posterior diameter	24·3mm.
Horizontal diameter	23·6mm.
Vertical diameter	23·4mm.
Diameter of cornea	12 mm.
Thickness of cornea at centre	·9mm.
,, ,, near margin	1·2mm.
,, posterior sclerotic	1.1mm. to 1·2mm.
,, anterior sclerotic	·7mm.
Breadth of iris after death	3·5mm. to 4·5mm.
Diameter of pupil...	4 mm.
Greatest thickness of ciliary muscle	·9mm.
Length of ciliary muscle	3·5mm.
Diameter of optic nerve behind eyeball —without sheath	3·4mm. to 3·8mm.
Diameter of same through sclerotic	1·5mm.
Thickness of lens	3·7mm.
Diameter of lens	10·3mm.

TABLE V.—Average Length and Weight of the External Ocular Muscles.

	Length.	Area of section of thickest part.	Weight.
Internal rectus... ...	40·8 mm.	17·39 sq. mm.	·747 gramme
External rectus ...	40·6 ,,	16·73 ,,	·715 ,,
Inferior rectus	40 ,,	15·85 ,,	·671 ,,
Superior rectus... ...	41·8 ,,	11·3 ,,	·514 ,,

TABLE VI.—Nerve Supply.

The 3rd cranial nerve supplies the superior rectus, internal rectus, inferior rectus, inferior oblique, levator palpebræ, iris, ciliary and choroid.

The 4th cranial nerve supplies the superior oblique.

The 5th cranial nerve supplies the iris, and probably the ciliary.

The 6th cranial nerve supplies the external rectus.

The cervical sympathetic controls the pupil.

Section III.

TABLE VII.—Conventional Magnification. The distance of distinct vision is 25 cms., the formula of Chapter XXIII. being used $\left(M = 1 + \frac{p-d}{f}\right)$

Power of Lens in Dioptres.	Distance of Lens from the Eye in cms.						
	1·5	2	4	6	8	10	12
80 D	19·8	19·4	17·8	16·2	14·6	13	11·4
40 D	10·4	10·2	9·4	8·6	7·8	7	6·2
20 D	5·7	5·6	5·2	4·8	4·4	4	3·6
16 D	4·7	4·6	4·3	4	3·7	3·4	3·1
12 D	3·76	3·70	3·47	3·23	3·00	2·76	2·52
10 D	3·35	3·30	3·10	2·90	2·70	2·5	2·30
8 D	2·88	2·84	2·68	2·52	2·36	2·2	2·04
6 D	2·38	2·35	2·23	2·11	2·00	1·88	1·76
4 D	1·94	1·92	1·84	1·76	1·68	1·60	1·52
3 D	1·69	1·67	1·61	1·55	1·50	1·44	1·38
2·5 D	1·58	1·57	1·52	1·48	1·42	1·37	1·32
2 D	1·47	1·46	1·42	1·38	1·34	1·30	1·26

Section IV.

TABLE VIII.—Approximate Percentage of Visual Conditions.

	Per Cent.
Emmetropia	4
Hyperopia	30
Myopia	4
Simple hyperopic astigmatism	10
Simple myopic astigmatism	2
Compound hyperopic astigmatism	45
Compound myopic astigmatism	3
Mixed astigmatism	2
	100

TABLE IX.—Deductions (in Hyperopia) from Corrections found Under Atropine.

1·00	deduct	0·25	Age, occupation and muscular balance to be considered in each case.
1·00 to 3·00	,,	0·50 to 0·75	
3·00 to 6·00	,,	1·00 to 1·50	
6·00 to 8·00	,,	1·75 to 3·00	

TABLE X.—Acquired Hyperopia from 55 to 85 Years.

Age	Acq. H.	Age	Acq. H.
55	0·25	72	1·50
60	0·50	74	1·75
65	0·75	76	2·00
68	1·00	78	2·25
70	1·25	80	2·50

TABLE XI.—Javal's Table of Objective Compared with Subjective Astigmatism; With and Against the Rule.

	Against the Rule.			With the Rule.					
Objective :	2·00	1·00	0·00	1·0	2·00	3·00	4·00	5·00	6·00
Subjective :	3·00	1·75	0·50	0·75	2·00	3·25	4·50	5·75	7·00

The objective astigmatism (in the upper line) has an average amount subjectively manifest indicated by the figures in the lower line immediately beneath.

TABLE XII.—Ophthalmometry.

Allowances to be made in Cylinders on account of the distance between the position of the lenses, as usually worn, and the cornea. *(After Carl Weiland.)*

Corneal Astigmatism. (By Ophthalmometer.)	Equivalent Cylinder. (Before the Eye.)
1·00 D.	+ 0·98 or — 1·014
2·00 D.	+ 1·94 ,, — 2·056
3·00 D.	+ 2·88 ,, — 3·130
4·00 D.	+ 3·75 ,, — 4·250
5·00 D.	+ 4·67 ,, — 5·370
6·00 D.	+ 5·54 ,, — 6·540
7·00 D.	+ 6·38 ,, — 7·750
8·00 D.	+ 7·20 ,, — 9·00

TABLE XIII.—Latent Hyperopia.

Age.	Average Hyperopia (Proportion Latent.)
10 Years	$\frac{3}{4}$ of total defect.
20 ,,	$\frac{1}{2}$,, ,, ,,
30 ,,	$\frac{1}{4}$,, ,, ,,
40 ,,	All manifest.

TABLE XIV.—Lenses Required in Aphakia, the Previous Defect Being Known. (*After Stadfeldt.*)

Condition before operation	H. 7	H. 5	H. 3	H. 1	E. 0	M. 1	M. 3	M. 5	M. 7	M. 9	M. 11	M. 13	M. 15	M. 17	M. 19	M. 21	M. 23	M. 25
Condition after operation	H. 15	H. 13·8	H. 12·5	H. 11·3	H. 10·6	H. 10·1	H. 8·9	H. 7·8	H. 6·6	H. 5·5	H. 4·4	H. 3·4	H. 2·3	H. 1·3	H. 0·2	M. 0·8	M. 1·8	M. 2·7

TABLE XV.—Equivalent Prisms to Metre Angles with P. D.'s from 50 to 70mm.

P. D. = twice base line.	Base line = ½ P. D.	Metre angles.	Value in degrees and minutes.
50 mm.	25 mm.	2·5 prism diop.	1° 26′
52 ,,	26 ,,	2·6 ,,	1° 29′
54 ,,	27 ,,	2·7 ,,	1° 32′
56 ,,	28 ,,	2·8 ,,	1° 36′
58 ,,	29 ,,	2·9 ,,	1° 40′
60 ,,	30 ,,	3·0 ,,	1° 43′
62 ,,	31 ,,	3·1 ,,	1° 46′
64 ,,	32 ,,	3·2 ,,	1° 50′
66 ,,	33 ,,	3·3 ,,	1° 53′
68 ,,	34 ,,	3·4 ,,	1° 57′
70 ,,	35 ,,	3·5 ,,	2° 0′

Equivalents for P. D. of 64mm.		
M. A.	Prism dioptres.	Degrees of arc.
1·00	3·2Δ	1° 50′
2·00	6·4Δ	3° 40′
3·00	9·6Δ	5° 30′
4·00	12·8Δ	7° 20′
5·00	16·0Δ	9° 10′
10·00	32·0Δ	18° 20′
20·00	64·0Δ	36° 40′

TABLE XVI.—Field of Vision. (F.O.V.)

Outward	90°	Upward	50°	Inward	60°	Downward	72°
Out and up	70°	Up and in	55°	In and down	55°	Down and in	85°

TABLE XVII.—Presbyopia: Reading Distance of 16 inches.

Age.	Amp.	P. P.	Correction	P. P. with lens (Approx.)	
40	4·50	22 c.m.	0·25	21 c.m.	The correction as indicated allows half the amplitude to be kept in reserve. Other tables for different distances may be constructed similarly.
45	3·50	28 ,,	0·75	24 ,,	
50	2·50	40 ,,	1·25	27 ,,	
55	1·50	66 ,,	1·75	30 ,,	
60	1·00	100 ,,	2·00	33 ,,	
65	0·50	200 ,,	2·25	36 ,,	
70	0·25	400 ,,	2·50	36 ,,	
75	0	∞	2·50	40 ,,	
80	0	∞	Reduced acuity renders uncertain.		

TABLE XVIII.—Hand Test Types. (*After Jaeger.*)

Hand Test Types	Snellen's Type. Type for.	Block size.
No. 1 should be "Diamond."	200 ft.	$3\frac{3}{4}$ in. square
,, 2 ,, ,, "Pearl."	160 ft.	3 in. ,,
,, 3 ,, ,, "Nonpariel."	120 ft.	$2\frac{1}{4}$ in. ,,
,, 4 ,, ,, "Minion."	100 ft.	$1\frac{7}{8}$ in. ,,
,, 5 ,, ,, "Brevier."	80 ft,	$1\frac{1}{2}$ in. ,,
,, 6 ,, ,, "Long Primer."	60 ft.	$1\frac{1}{8}$ in. ,,
,, 7 ,, ,, "Small Pica."	40 ft.	$\frac{3}{4}$ in. ,,
,, 8 ,, ,, "Pica."	30 ft.	$\frac{9}{16}$ in. ,,
,, 9 ,, ,, "Two line Brevier."	20 ft.	$\frac{3}{8}$ in. ,,
,, 10 ,, ,, "Two line Long Primer."	15 ft.	$\frac{9}{32}$ in. ,,
,, 11 ,, ,, "Two line Pica."	10 ft.	$\frac{3}{16}$ in. ,,
,, 12 ,, ,, "Three line Pica."		
,, 13 ,, ,, "Four line Pica."		
,, 14 ,, ,, "Five line Pica."		

TABLE XIX.—Effect of Inclination or Tilting on a Lens of 1 D.

Angle.	SPHERICAL. Equivalent sph. cyl.	CYLINDRICAL. Equivalent cyl.
5°	1·002 D sph. ○ ·007 D cyl.	1·009 D cyl.
10°	1·009 D „ ○ ·032 D „	1·041 D „
15°	1·023 D „ ○ ·073 D „	1·096 D „
20°	1·040 D „ ○ ·138 D „	1·178 D „
25°	1·065 D „ ○ ·231 D „	1·296 D „
30°	1·094 D „ ○ ·365 D „	1·459 D „

The effect upon any lens may be obtained from the above by multiplying by the number of dioptres in the lens.

TABLE XX.—Curvatures of Lens Surfaces for True Periscopic Effect.

+ Power.	Surface facing the Light.	Surface facing the Eye.	— Power.	Surface facing the Light.	Surface facing the Eye.
+ 1D	+ 6D	- 5D	- 1D	+ 5·5D	- 6·5D
+ 2D	+ 8D	- 6D	- 2D	+ 5D	— 7D
+ 3D	+ 10D	- 7D	- 3D	+ 4·5D	— 7·5D
+ 4D	+ 12D	- 8D	- 4D	+ 4D	— 8D
+ 5D	+ 13D	- 8D	- 5D	+ 3·5D	— 8·5D
+ 6D	+ 15D	- 9D	- 6D	+ 3D	- 9D
+ 7D	+ 16·5D	- 9·5	- 7D	+ 2·5D	— 9·5D
+ 8D	+ 17·75D	- 9·75D	- 8D	+ 2D	— 10D
+ 9D	+ 19·5D	- 10·5D	- 9D	+ 1D	— 10D
+ 10D	+ 21D	- 11D	- 10D	Plano	— 10D
+ 12D	+ 23D	- 11D	- 12D	Plano	— 12D
+ 15D	+ 27D	- 12D	- 14D	Plano	— 14D
			- 16D	— ·5D	— 16·5D

Section V.

TABLE XXI.—Deviation Constants.

Prisms are measured in three ways :—

1. By the *angle at the apex* (or refracting angle) contained by the sides of the glass, and written in degrees, viz., 1°, $1\frac{1}{2}$° or 1° 30′. The size of this angle varies with *n* of the glass for the same deviation. (See below.)

2. By the *angular deviation* produced by the prism, which will be nearly half the apical angle. This is also written in degrees, and should have "d" added to it to distinguish it from the first, viz., 1°d, 2°d.

3. By *prism dioptres*, which express linear deviation, the unit being a prism which deviates a ray of light 1cm. from its path at a distance of 1 metre. Written 1^{Δ}, 2^{Δ}, etc. (The *centrad* is practically the same measurement.)

1^{Δ}	= 1·00 cm.	1° (n = 1·57)	= 1·00 cm. (10·0 mm.)
1° (n = 1·5)	= 0·87 ,,	1° (n = 1·60)	= 1·06 ,, (10·6 ,,)
1° (n = 1·54)	= 0·94 ,,	1°d	= 1·745 ,, (17·45 ,,)

Prisms (n = 1·54).		
Angle of Dev.	Angle of Ref.	Linear Dev. (At 1m.)
0·5	0·93	8·6 mm.
1·0	1·85	17·4 ,,
1·5	2·78	26·2 ,,
2·0	3·70	34·8 ,,
2·5	4·63	43·6 ,,
3·0	5·55	52·4 ,,
3·5	6·48	61·2 ,,
4·0	7·40	69·8 ,,
5·0	9·23	87·4 ,,
6·0	11·5	105·0 ,,
7·0	12·58	122·8 ,,
8·0	14·63	140·2 ,,

Prisms (n = 1·54).	
Prism Diop.	Ref. Ang.
$1·00^{\Delta}$	1·06°
$2·00^{\Delta}$	2·16°
$3·00^{\Delta}$	3·24°
$4·00^{\Delta}$	4·32°
$5·00^{\Delta}$	5·40°
$6·00^{\Delta}$	6·47°
$7·00^{\Delta}$	7·54°
$8·00^{\Delta}$	8·62°

TABLE XXII.—Decentration Formulæ. (*Approximate.*)

(*a*) For every cm. of decentration in a lens as many prism dioptres are produced as the lens has D. of refraction (see Chap. XLV.).

(*b*) A decentration of $\frac{1}{100}$th inch for every inch of focal length of the lens gives a 1° refracting angle.

To convert prism dioptres to degrees of angular deviation (degrees of arc) we see from Table XXI. $\frac{1^{\Delta}}{1^{\circ}\,d} = \frac{1}{1{\cdot}745}$ $(n = 1{\cdot}53)$

$$\text{so that} \quad 1^{\Delta} = \frac{1^{\circ}\,d}{1{\cdot}745} = {\cdot}573^{\circ}\,d$$

The ratio between the refracting angle of a prism ($n = 1{\cdot}54$) and the angular deviation produced is $\frac{0{\cdot}94}{1{\cdot}745}$ (Table XXI.) or ·53 (about $\frac{1}{2}$), so that $1^{\circ} = {\cdot}53^{\circ}$ d.

This may be more exactly expressed as below, by which n may also be determined.

Angle of deviation produced = $(n - 1) \times$ Refracting angle of the prism.

The following table is obtained by multiplying the number of degrees of refracting angle ($n = 1{\cdot}54$) by 0·94 and dividing by the number of D. in the lens. The result is the decentration required in mm.

		1°	2°	3°	4°	5°	6°	8°
Lens =	1 D.	9·4 mm.	18·8	28·3	37·7	47·2	56·5	75·8
,,	2 D.	4·7	9·4	14·1	18·8	23·6	28·2	37·9
,,	3 D.	3·1	6·3	9·4	12·6	15·7	18·8	25·3
,,	4 D.	2·3	4·7	7·1	9·4	11·8	14·1	18·9
,,	5 D.	1·9	3·8	5·7	7·5	9·4	11·3	15·2
,,	6 D.	1·6	3·1	4·7	6·3	7·9	9·4	12·6
,,	etc.							

TABLE XXIII.—For marking a card in tangents of degrees of deviation at 25cms., 1m., 2m., 6m.

	At 25cm.	At 1m.	At 2m.	At 6m.
1°d	·43cm.	1·74cm.	3·49cm.	10·47cm.
2°d	·89	3·49	6·98	20·94
3°d	1·30	5·23	10·467	31·40
4°d	1·71	6·87	13·95	41·86
5°d	2·17	8·71	17·43	52·29
6°d	2·61	10·45	20·90	62·80
7°d	3·04	12·18	24·37	73·12
8°d	3·47	13·91	27·83	83·50
9°d	3·91	15·64	31·29	93·88
10°d	4·34	17·36	34·73	104·20
11°d	4·77	19·08	38·16	114·49
12°d	5·19	20·79	41·58	124·75
13°d	5·62	22·49	44·99	134·98
14°d	6·04	24·19	48·38	145·15
15°d	6·47	25·88	51·76	155·29
16°d	6·89	27·56	55·13	165·40

TABLE XXIV.—Equivalents in Grains, Grammes and oz. (Troy).

1 Grain = 0·0648 Grammes.

1 Gramme = 15·43 Grains = 0·32 oz. Troy.

1	dwt.	0	grains	=	1·5552	grammes	=	·05	oz. (Troy).
1	,,	6	,,	=	1·94	,,	=	·062	,,
1	,,	12	,,	=	2·33	,,	=	·075	,,
1	,,	18	,,	=	2·72	,,	=	·087	,,
2	,,	0	,,	=	3·11	,,	=	·100	,,
2	,,	6	,,	=	3·49	,,	=	·112	,,
2	,,	12	,,	=	3·88	,,	=	·125	,,
2	,,	18	,,	=	4·27	,,	=	·137	,,
3	,,	0	,,	=	4·66	,,	=	·150	,,
3	,,	6	,,	=	5·05	,,	=	·162	,,
3	,,	12	,,	=	5·44	,,	=	·175	,,
3	,,	18	,,	=	5·83	,,	=	·187	,,
4	,,	0	,,	=	6·22	,,	=	·200	,,
4	,,	6	,,	=	6·61	,,	=	·212	,,
4	,,	12	,,	=	6·99	,,	=	·225	,,
4	,,	18	,,	=	7·38	,,	=	·237	,,
5	,,	0	,,	=	7·77	,,	=	·250	,,
5	,,	6	,,	=	8·16	,,	=	·262	,,
5	,,	12	,,	=	8·55	,,	=	·275	,,
5	,,	18	,,	=	8·94	,,	=	·287	,,
6	,,	0	,,	=	9·33	,,	=	·300	,,

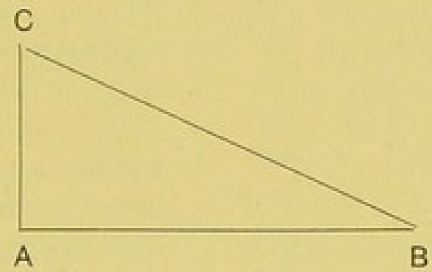
TABLE XXV.—Metric and English Linear Equivalents.

To convert	inches to millimetres	multiply by	25·4	(Roughly—multiply by 100 and divide by 4)
,,	mm. to inches	,,	0·03937	(Roughly—multiply by 4 and divide by 100)
,,	metres to feet	,,	3·2808	(Roughly—multiply by 10 and divide by 3)
,,	feet to metres	,,	0·3048	(Roughly—multiply by 3 and divide by 10)

To reduce French inches to English × 39·37 and ÷ 37.

135·3 French lines = 1 foot.

CALCULATION for Resultant Prisms :—



Let A B = in cm. the °d. of the horizontal prism.

,, A C = in cm. the °d. of the vertical prism.

Then C B = in cm. the °d. of the resultant prism.

And A B C = angle of the "base apex line" with the horizontal (or by calculation)

(1) Square the vertical prism.

(2) Square the horizontal prism.

(3) Add the two, and extract the square root, this is the *power* of the resultant prism.

Then :—

$$\frac{\text{Horizontal effect required}}{\text{Power of resultant prism}} = \left\{ \begin{array}{l} \textit{Cosine of} \text{ the angle of rotation} \\ \text{of the base apex line from the} \\ \text{horizontal.} \end{array} \right.$$

To find the effects (V. and H.), of an oblique prism :—

Sine of angle of rotation from the horizontal × °d. of the oblique prism = the vertical effect.

Similarly :—

Cosine of the *same* angle × °d. of the oblique prism = the horizontal effect.

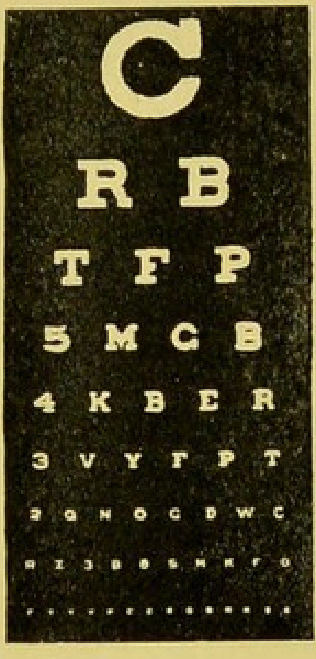
Index.

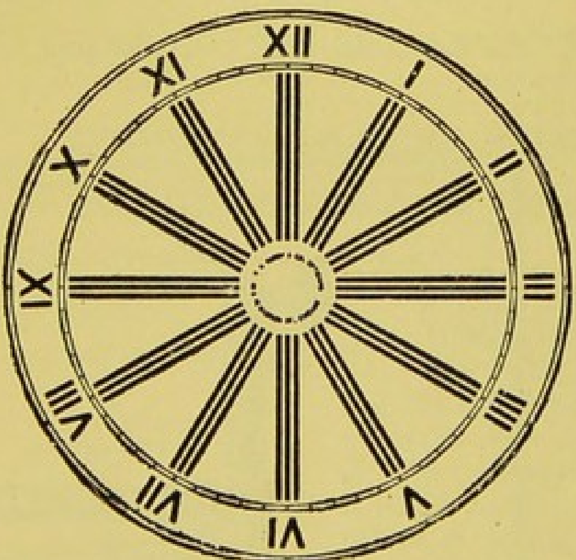
B

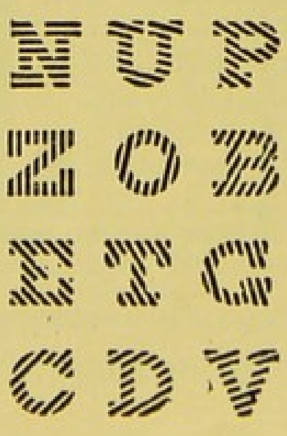
C

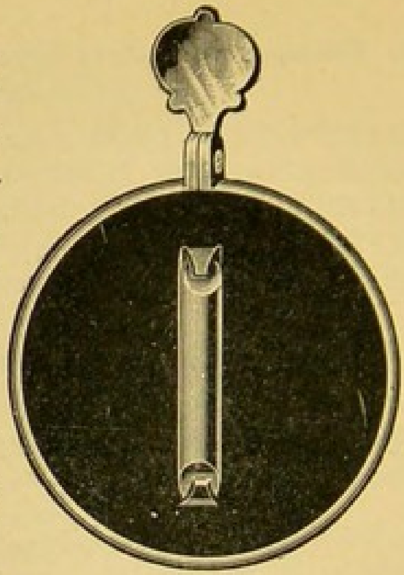
The following list gives the prices at which many useful articles may be purchased :—

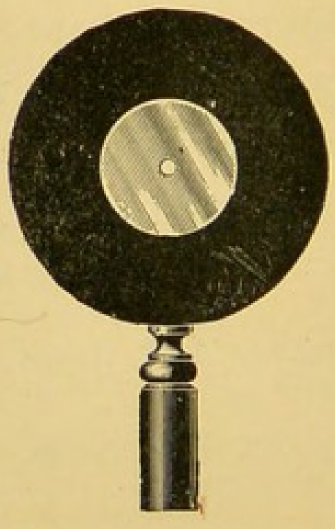
No.	Article	£	s.	d.
1.	SNELLEN'S TEST TYPE, four different sheets, various letters and arrangements, paper 21 inches by 9 ... ... per sheet	0	0	6
2.	SNELLEN'S TEST TYPE, four different sheets, on cards with metal edge to top ... ... per card, 1/- ; per set	0	4	0
3.	SNELLEN'S TEST TYPE, reversed for use with Mirror ... per card	0	1	0
4.	TEST TYPE, white letters on black ground (as illustrated) ... ... per card	0	1	3
5.	SNELLEN'S READING TYPE, 8 × 5½, distances in feet	0	0	6
6.	JAEGER'S TEST TYPE, folding 14 × 11, distances in centimetres	0	0	9
7.	THE "ORTHOPS" CHART—			
	Ordinary Type, 40 × 25	0	9	6
	Reversed Type	0	10	6
	Portable Chart, 1½ × 12½	0	7	6
	2 extra cards for changing type	0	2	0
8.	ASTIGMATIC FAN, Large size paper	0	1	6
9.	ASTIGMATIC FAN, Linen, mounted on rollers... ...	0	3	0
9A.	ASTIGMATIC FAN-CARD...	0	1	0
10.	ASTIGMATIC CLOCK FACE (as illustrated), 18 × 18 ...	0	1	0
10A.	ASTIGMATIC STAR ...	0	0	6
11.	TEST TYPE (after Dr. Pray) for Astigmatism, circles ...	0	0	6
12.	TEST TYPE (after Dr. Pray) for Astigmatism, letters (as illustrated)	0	1	6
13.	PINHOLE DISC, black bronzed metal, in nickelled steel frame, with ebony handle ...	0	2	0
14.	STENOPAIC SLIT, mounted as above ...	0	2	0
15.	STENOPAIC SLIT, adjustable for various widths	0	3	6
16.	REVOLVING SLITS & PINHOLES of various sizes, with spring clip and groove for holding lens	0	6	0





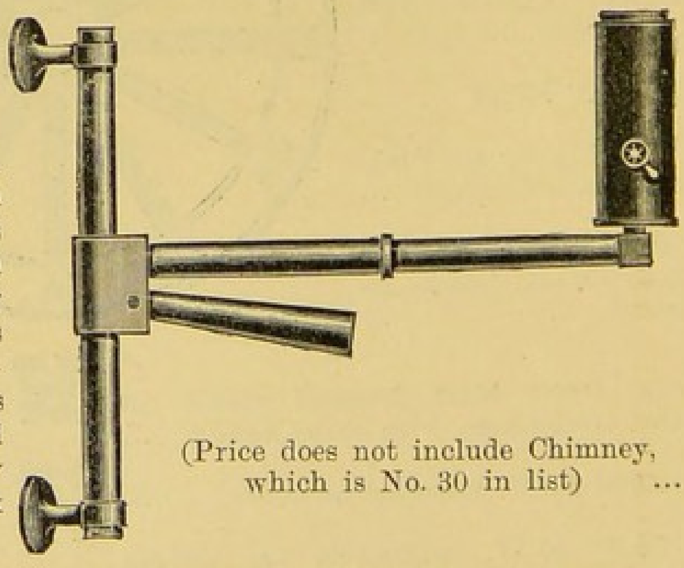






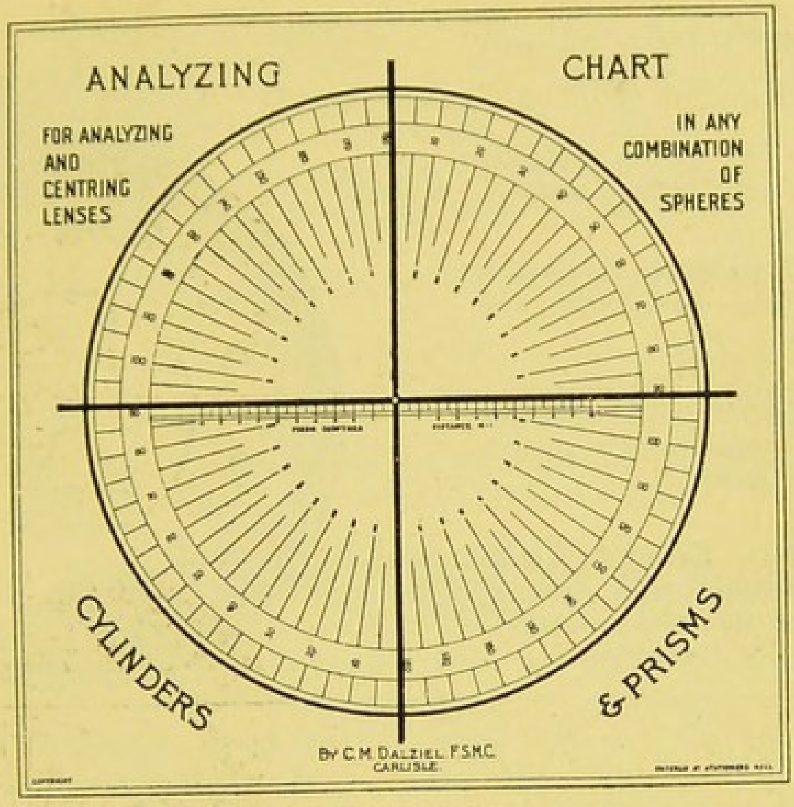
No.	Article	£	s.	d.
17.	DISC OR LENS HOLDER, nickelled steel, ebony handle	0	1	0
18.	TEST RING, with vivid blue, green, or opaque glass	0	1	0
19.	MADDOX ROD for testing muscular insufficiency (*as illustrated*)	0	1	6
20.	MADDOX MULTIPLE ROD for testing muscular insufficiency	0	2	6
21.	MADDOX PRISM mounted in Test Ring...	0	2	0
22.	CHROMATIC TEST in nickelled ring, with handle	0	1	9
23.	JACKSON'S CROSSED CYLINDER in nickelled ring, with handle	0	2	6
24.	NEAR POINT MEASURE, boxwood ...	0	5	0
25.	TEST CARDS for Near Point Measure...	0	0	6
26.	RETINOSCOPE, plain or concave mirror, with ebony handle...	0	2	6
27.	THORINGTON'S RETINOSCOPE ... (*as illustrated.*)	0	4	6
28.	QUEEN'S PRACTISE EYE for practising Retinoscopy...	0	2	6
29.	ASBESTOS RETINOSCOPIC CHIMNEY	0	6	0
30.	ASBESTOS RETINOSCOPIC CHIMNEY, with Iris Diaphragm ...	0	10	0

30A. MACKINNEY'S OPHTHALMIC BRACKET, with electric or gas fittings. This is very simple in construction, and is self-fixing in position by merely releasing the handle which is attached to an eccentric cam. The bars are telescopic, and the whole is highly finished in dead black

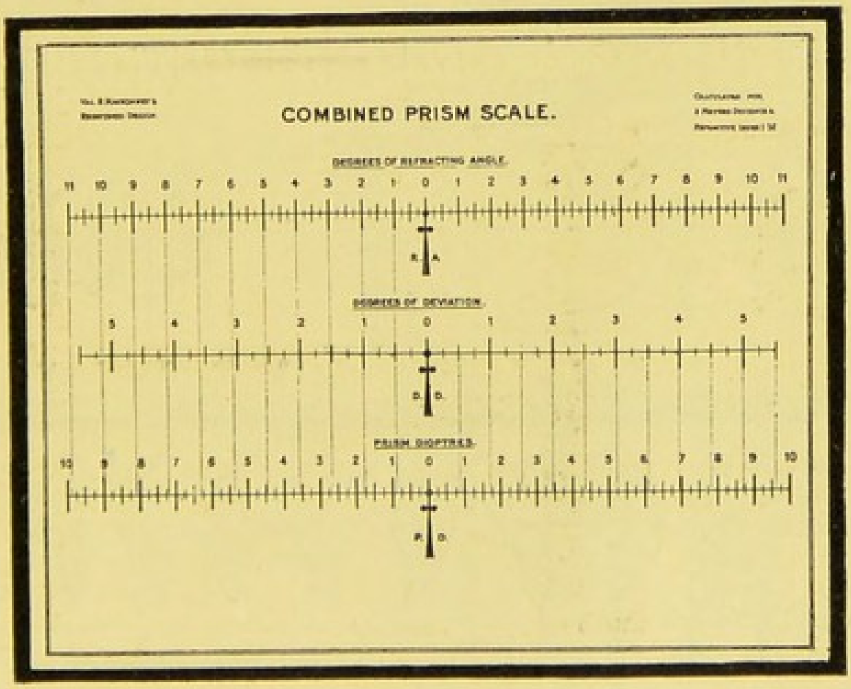


(Price does not include Chimney, which is No. 30 in list) ... 1 12 6

No.	Article	£	s.	d.
31	MORTON'S OPHTHALMOSCOPE, best English make	2	12	6
32.	MORTON'S OPHTHALMOSCOPE, foreign make (to order only) ...	2	7	6
33.	MANIFOLD PRESCRIPTION BOOKS, of 100 pages...	0	1	6



	£	s.	d.
34. DALZIEL'S CHART for analyzing and centering lenses (*as illustrated*)	0	3	6



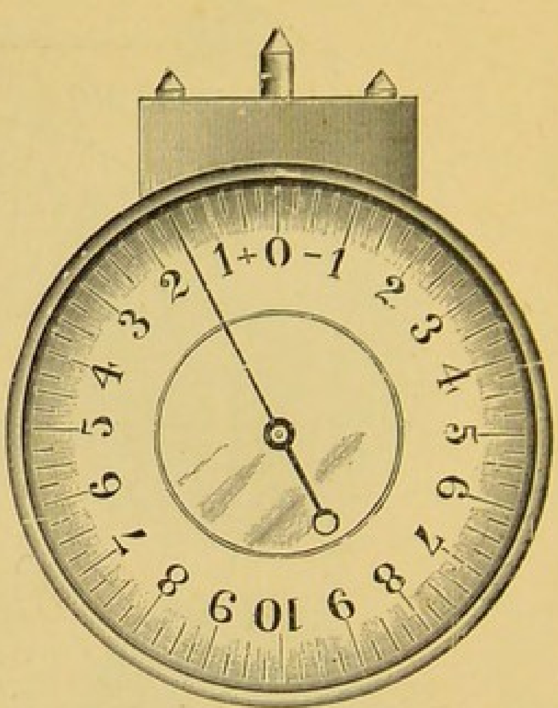
	£	s.	d.
34A. MACKINNEY'S PRISM CHART, for testing the prismatic power of a lens in D of R.A, D of D and P.D. Also useful for testing muscular imbalance at a near distance	0	2	0

s. d.

35. CONDENSING LENS, diameter $2\frac{1}{2}$-in., $2\frac{1}{2}$ or 3 inch focus ... 1 6

36. CONDENSING LENS, diameter $2\frac{1}{2}$-in., in strong nickel mount... 3 6

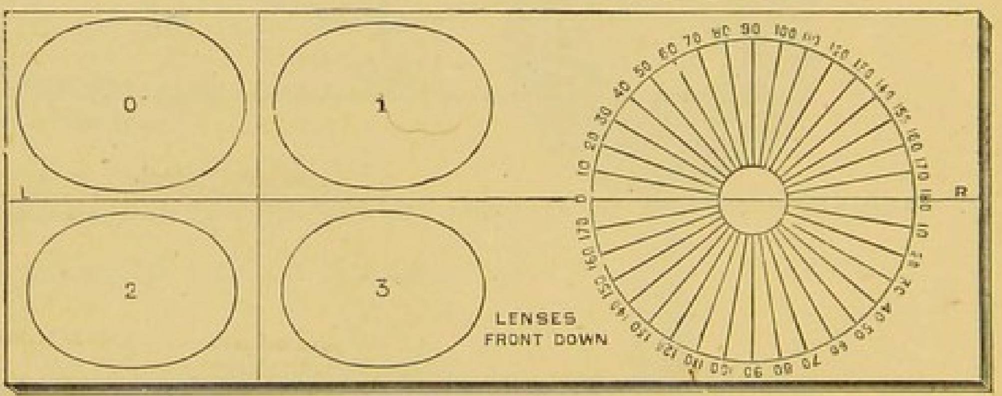
37. LENS MEASURE (*as illustrated*), for testing cylindrical and spherical lenses 17 6

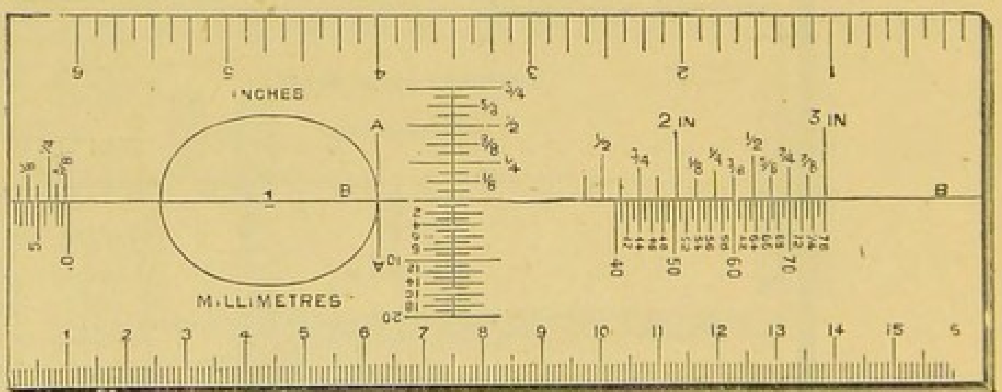


38. The SPHEROMETER, a cheaper form of measure for testing spherical lenses... ... ... 14 6

39. BOXWOOD SCALE, with centering cross, and reversed protractor for testing axes of cylinders (*as illustrated*) ... 1 6

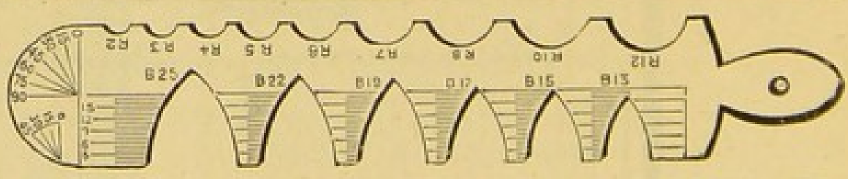
40. SPECTACLE FRONT MEASURE, for testing heights, projection, and centres of spectacles with analyzing scale on reverse. (*as illustrated*) s. d. 2 6



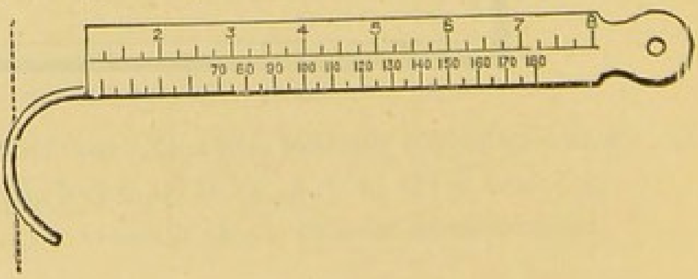


41. NOSE CONTOUR MEASURE. (*Regd.*) A device by which the contour of any nose can be expressed in three measurements, from which a spectacle bridge can be made exactly to fit. (*As illustrated.*)

	s.	d.
Boxwood	3	6
Celluloid	4	0

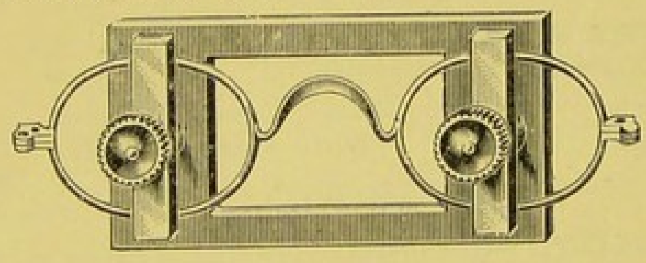


42. CURL SIDE MEASURE (*As illustrated*) ... 4 0

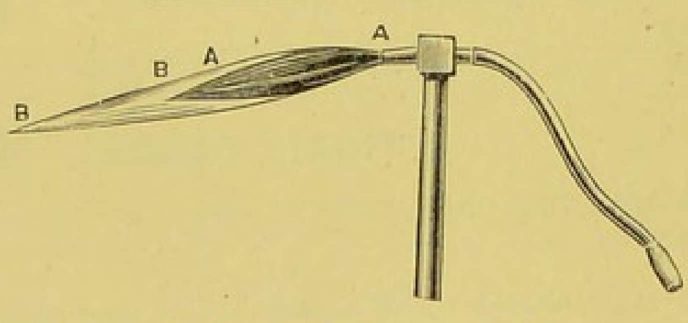


		£	s.	d.
43.	FOLDING BOXWOOD METRE RULE, folds into 5½ inches, marked in millimeters and inches	0	1	0
44.	SET OF SIX TRIAL FRAMES, centres 2⅛ to 2⅝ inches, with six different bridges, ticketted with details on each. Empty. ...The set	0	9	0
45.	SET OF SIX TRIAL FRAMES, centres 2⅛ to 2½ inches, with six different bridges, measurements on ends in gilt letters. Empty. The set	0	12	0
46.	SET OF SIX TRIAL FRAMES, glazed, measurements on ends in gilt letters	0	18	0
47.	SET OF TWELVE TRIAL FRAMES, centres 2 inch to 2⅝, in polished walnut case, with separate division for each centre, measurements marked on frame in gilt letters ... ...The set	1	7	0
48.	JOINT HOLDER *(as illustrated)* for holding spectacle joints while screw is turned, preventing injury to frame	0	0	9

		£	s.	d.
49.	SCREW DRIVERS (OPTICIANS'), two sizes, for ordinary and fine joints, with strong handle ... ... each	0	0	6
50.	SCREW DRIVERS, high quality, two sizes, one for Gold work, recommended... ... ... each	0	1	3
50A.	SCREW SLOTTER, for cutting new slots in screw heads... ...	0	0	8
51.	BRASS SOLDERING CLIP *(as illustrated)* for holding spectacle frame during repair.	0	1	6

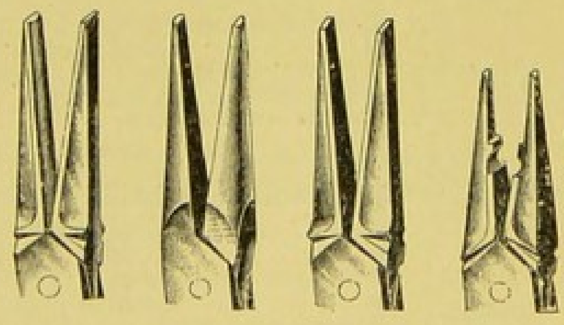


		£	s.	d.
52.	BLOW PIPE, flexible *(as illustrated)* very useful for repairs.	0	2	0



53. SET OF OPTICIANS' PLIERS *(as illustrated)*. consisting of one pair each, flat nose, half-round nose, sharp nose, and shaped and slotted nose, for holding spectacle or eyeglass joints, well nickel-plated.

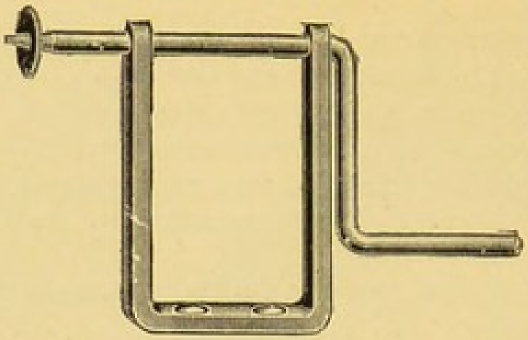
	s.	d.
Per pair ...	1	6



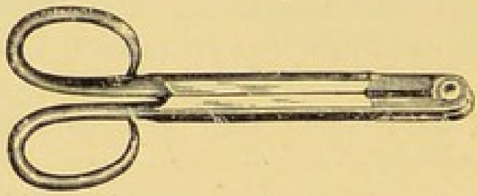
The set, 0 6 0

		£	s.	d.
54.	The same SET OF PLIERS, in polished case, complete with flat file, three-square file, and two screw drivers (one broad and one narrow), forming a very useful set of tools for an optician ... per case	0	13	6
55.	Or with best quality drivers	0	15	0

	£ s. d.
55a. MILLED WHEEL, for clearing eyewires of solder or rough parts. Made to screw on work bench or fit in vice.	0 2 6



56. GAUGE RINGS (American make, guaranteed accurate) for sizing interchangeable lenses	0 1 6
57. GAUGE PLATES (American make, guaranteed accurate) for testing frames	0 3 6
58. TOURMALINE PINCETTE for testing pebbles	0 5 0
59. SHANKS OR NIPPERS for edging Spectacle lenses, previous to grinding	0 1 6



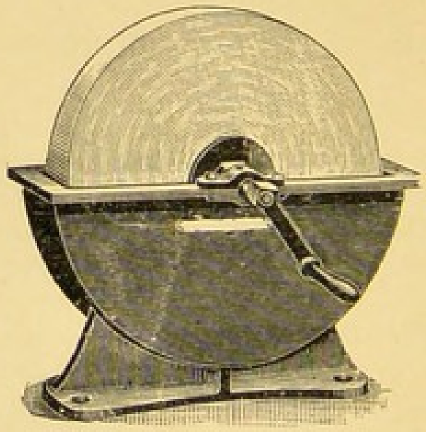
60. BILSTON OR ADAMANT GRINDSTONE, (*as illustrated*) iron trough—

12 x 2	14 x 2½	16 x 3	18 x 3	20 x 3
12/-	14/6	17/-	26/-	31/-

Larger sizes quoted for.

61. CRAIGLIETH GRINDSTONE, in iron trough—

12 x 1	14 x 1	16 x 1	18 x 1	20 x 1
19/-	23/-	28/6	40/-	48/6



TRIAL CASES.

	£ s. d.
POLISHED WALNUT CASE, with 18 convex and 18 concave cylinders, ·25 to 5·50	1 1 0

POLISHED MAHOGANY CASE, detachable lid, lined with satin.

Contents:
- 32 pairs spherical c/x ·25 to 20 D.
- 32 ,, ,, c/c ·25 to 20 D.
- 6 plano tinted glasses
- 2 discs (pinhole and slit)
- 1 single cell trial frame 2 10 0

POLISHED MAHOGANY CASE, detachable lid, lined with satin, good lock.

Contents:
- 30 pairs spherical c/x ·25 to 20 D.
- 30 ,, ,, c/c ·25 to 20 D.
- 18 single cylinders c/x ·25 to 7 D.
- 18 ,, ,, c/c ·25 to 7 D.
- 8 plano tinted glasses
- 4 discs (stenopaic slit, pin-hole, etc.)
- 1 single cell trial frame
- 1 two cell graduated trial frame 3 18 0

POLISHED WALNUT CASE, fixed lid, contents as above 4 4 0

£ s. d.

POLISHED MAHOGANY CASE, detachable lid, lined satin, brass fittings and good lock, all lenses mounted in test rings with pierced handles.

Contents:
- 30 pairs spherical c/x ·25 to 20 D.
- 30 „ „ c/c ·25 to 20 D.
- 18 single cylinders c/x ·25 to 7 D.
- 18 „ „ c/c ·25 to 7 D.
- 12 prisms 1^{A} to 12^{A}
- 12 plano blue and smoke glasses
- 1 each plano red, white, green and yellow glasses
- 4 discs (stenopaic slit, pin-hole, etc.)
- 1 single cell trial frame
- 1 two cell graduated trial frame 7 0 0

POLISHED MAHOGANY CASE, detachable lid, lined satin, brass fittings and good lock.

Contents:
- 32 pairs spherical c/x ·25 to 20 D.
- 32 „ „ c/c ·25 to 20 D.
- 18 pairs cylinders c/x ·25 to 7 D.
- 18 „ „ c/c ·25 to 7 D.
- 12 prisms 1^{A} to 12^{A}
- 12 plano blue and smoke glasses
- 1 each plano red, green, amber, and white
- 4 discs (stenopaic slit, pin-hole, etc.)
- 1 chromatic test
- 1 single cell trial frame
- 1 two cell graduated trial frame

All lenses mounted in fine test rings, with pierced handles 8 8 0

POLISHED MAHOGANY CASE, highly finished with bevelled plate glass top, removable lid, tray for lenses to lift out, good fittings and lock.

Contents:
- 30 pairs spherical c/x ·25 to 20 D.
- 30 „ „ c/c ·25 to 20 D.
- 18 single cylinders c/x ·25 to 7 D.
- 18 „ „ c/c ·25 to 7 D.
- 12 prisms 1^{A} to 12^{A}
- 12 blue and smoke glasses
- 1 each plano ruby, amber, green, and white
- 4 discs
- 1 single cell trial frame
- 1 double cell graduated trial frame

All lenses in fine test rings, with pierced handles 8 0 0

POLISHED MAHOGANY CASE, highly finished, with bevelled plate glass top, removable lid, tray for lenses to lift out, good fittings and lock.

Contents:
- 32 pairs spherical c/x ·25 to 20 D.
- 32 „ „ c/c ·25 to 20 D.
- 18 pairs cyl nders c/x ·25 to 7 D.
- 18 „ „ c/c ·25 to 7 D.
- 12 prisms 1^{A} to 12^{A}
- 12 plano blue and smoke glasses
- 1 each plano red, amber, green, and white
- 5 discs
- 1 chromatic test
- 1 Maddox rod
- 1 single cell trial frame
- 1 double cell graduated trial frame 9 16 0

LEATHER COVERED, finely finished case, with velvet and leather fittings, all lenses mounted in tempered spun rims, and nickel plated.

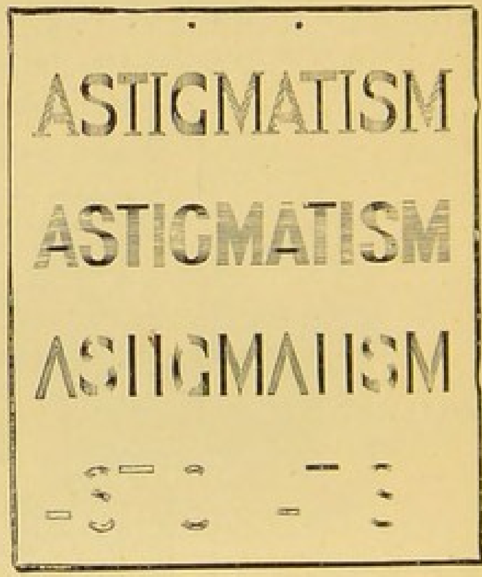
Contents:
- 32 pairs spherical c/x ·12 to 20 D.
- 32 „ „ c/c ·12 to 20 D.
- 20 pairs cylinders c/x ·12 to 6 D.
- 20 „ „ c/c ·12 to 6 D.
- 10 prisms 1^{A} to 10^{A}
- 3 coloured glasses
- 1 Maddox rod
- 6 stenopaic and occluding discs
- 1 double cell graduated trial frame
- 1 single cell trial frame 9 0 0

or with best standard trial frame, adjustable sides ... 10 0 0

WORKS ON OPTICS.

		£	s.	d.
HARTRIDGE—"Refraction of the Eye"	... ...	0	5	0
"The Ophthalmoscope"	... ...	0	4	0
KEYSTONE—"The Optician's Manual"	... ...	0	6	3
"The Optician's Manual Supplement"	... ...	0	3	4
"Skiascopy"	... ...	0	4	2
TAYLOR—"The Manipulation and Fitting of Ophthalmic Frames"	...	0	4	0
THOMPSON—"Optical Tables and Data"	... ...	0	6	0
LAURANCE—"The Eye" (Physiological and Anatomical)	... ...	0	3	6
"General and Practical Optics"	... ...	0	10	6
MACKINNEY & TAYLOR—"Geometrical Optics"	... ...	0	2	6

CHARTS FOR ADVERTISING PURPOSES.

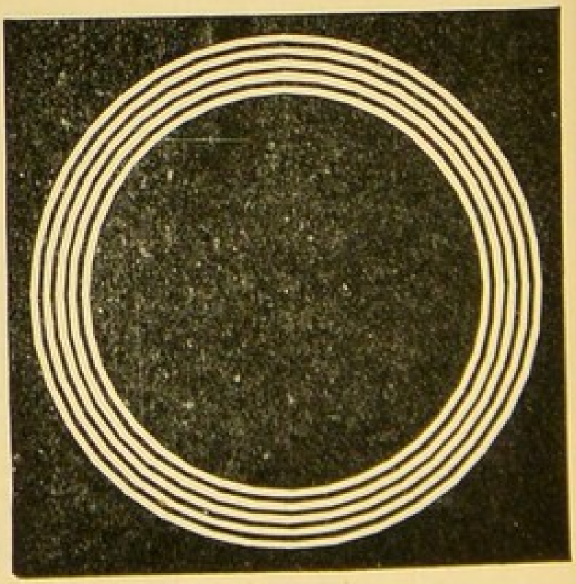


This Chart illustrates the relative value of vertical and horizontal lines in deciphering letters, and provides a good means of explaining to clients the significance of astigmatism.

The first and second lines illustrate the difference between a word having the horizontal components of the letters blurred, and one in which the vertical positions are indistinct.

In the third only vertical lines are shown, and in the fourth horizontal.

1/- each.



A set of three charts, consisting each of a series of tangents (at 10° intervals) to concentric circles. These charts are printed in black, red, and blue, and are delicate tests for irregular astigmatism, besides illustrating (by the different extent of the blurring) the chromatic aberration of the eye.

1/- each ; 2/6 the set of three.

NEWBOLD & BULFORD,

46 & 48, Goswell Road, E.C.

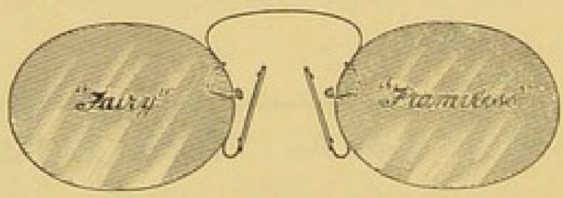
— THE —

PRESCRIPTION HOUSE.

Inventors and Patentees

OF

"FAIRY" EYEGLASSES



And many other well-known Optical articles.

MANUFACTURERS OF

Spectacles and Eyeglasses in Gold, Gold-Filled, Nickel, and Steel. Lenses, etc., etc.

Telephones:—898 London Wall.
1484 Central.

Telegrams:—
BULFORD, LONDON.

NEWBOLD & BULFORD.

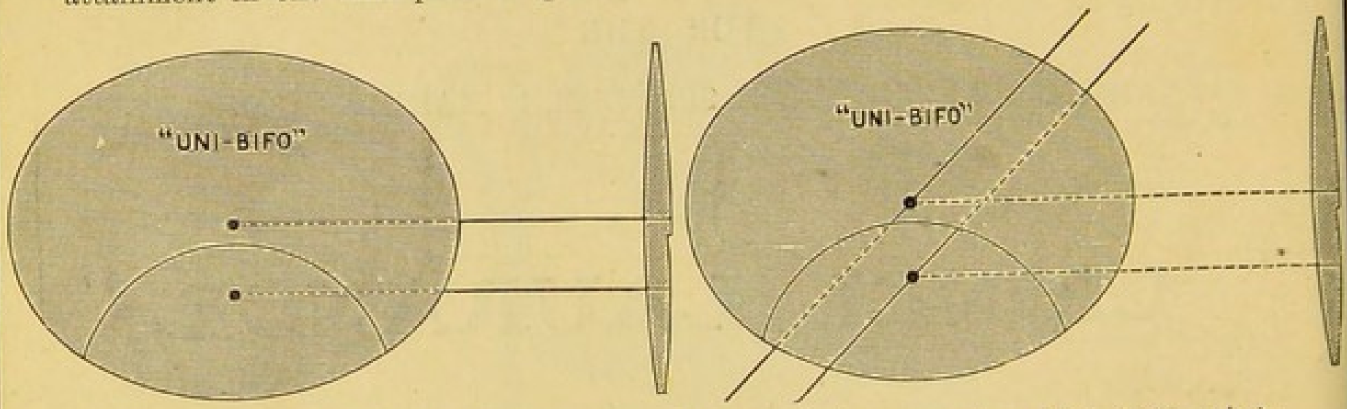
THE UNI-BIFOCAL COMPANY, LIMITED,

MANUFACTURERS OF

"UNI-BIFO" & "LUXE" LENSES

(Protected by Royal Letters Patent and Trade Marks.)

The solid down-curve bifocal lens, known by the trade mark, "Uni-Bifo," has marked a new era in Ophthalmic Refraction work. The new method of lens grinding employed permits of bifocal lenses being produced with mathematical precision and with a perfection of optical detail and finish never before believed possible of attainment in one solid piece of glass.



Will cut 00. (40 × 12 m/m). Distance between centres ¼ in. (6·25 m/m).

The Principal Advantages of the "Uni-Bifo" Lenses are:

1. **A solid One-piece Bifocal.**
2. **Perfect Centreing** of each portion of the lens, even in sph. cyl. combinations with oblique axes.
3. **Perfectly worked surfaces.**
4. **Freedom from chromatic aberration.**
5. **Correct decentration.** The centres of either portion may be placed at will where desired.

Prescriptions that may be filled in "Uni-Bifo" Lenses:

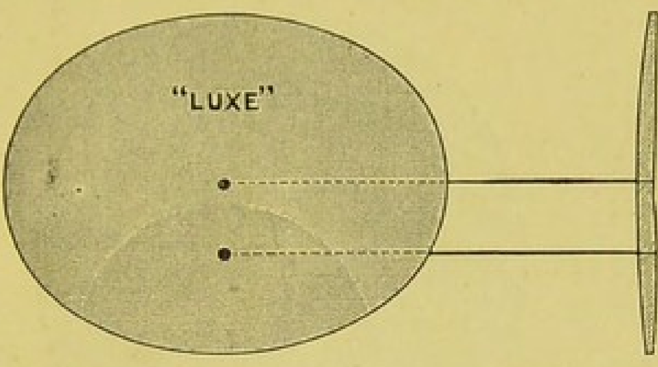
1. Any two spherical powers.
2. Any spherical power combined with cyl. or toric.
3. Any mixed combination of − and + powers.
4. Any degree of prism in distance or reading portion, or both.
5. Lenses with cyl. on distance portion only.
6. Sphero Cylindrical Lenses with parallel axes.
7. Lenses with different cyls. on reading portion to that of distance portion (provided there be no spherical power in distance portion).
8. Lenses with any power added for reading.

"UNI-BIFO" LENSES ARE MADE IN ALL THE ORDINARY FORMS AND TINTS.

188, STRAND, LONDON, W.C.

THE "LUXE" BIFOCAL.

This lens represents absolute perfection in solid bifocal workmanship. The two portions in the "Uni-Bifo" lens are ground in such a way that the ridge dividing the two foci entirely disappears, giving the lens the appearance of an ordinary spectacle lens, hence the term "Invisible."



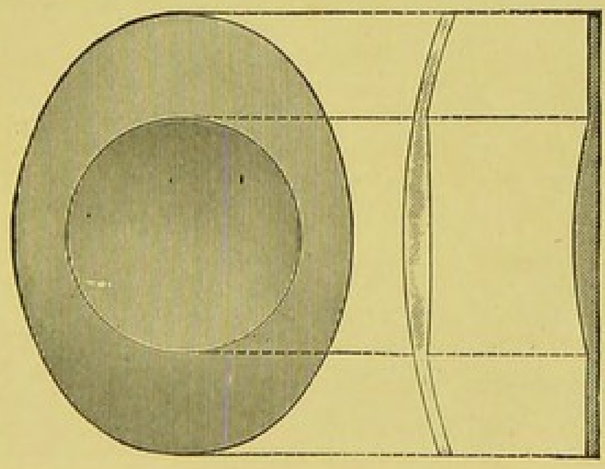
Size of reading portion varies slightly according to the combination.

The "Luxe" lens is made from one piece of glass—has one index of refraction only—is free from chromatic aberration, and from the risk of bursting. It is made in all convex combinations and in mixed − and +, provided the distance power is positive in the vertical meridian.

THE "LUXE" LENTICULAR.

(Featherweight Cataract Lens.)

This lens is produced by the same method, and is practically free from the unpleasant effect due to reflection. It is undoubtedly the finest cataract lens made from one piece of glass ever produced, and the weight is only about one-third of that of an ordinary lens.



It can be made in plano, convex, periscopic, deep periscopic, cylindrical and toric form.

The deep periscopic lens can be made with a − 6·00 D. base, the still deeper spherical curve in that case being on the outside.

MEDICAL PRESS OPINIONS.

"KLINISCHE MONATSBLÄTTER FÜR AUGENHEILKUNDE."

The ideal "Uni-Bifo" formerly referred to has recently been introduced. . . . . There is no ridge dividing the two foci, but the distance portion and the reading portion merge into one another in such a way that THERE ARE NO DISTURBING PRISMATIC OR CHROMATIC EFFECTS. This lens is called the "Luxe" Uni-Bifo. . . . . It seems impossible to conceive a more practical bifocal ever being invented.

"THE OPHTHALMOSCOPE."

In the "Luxe" model submitted to us, the defects of the cemented lens seem to have been completely overcome. We have examined several samples of these lenses and fail to find the least trace of aberration. It is an essential advantage that the dividing line is practically invisible, giving the lens the appearance of an ordinary spectacle lens.

"OPHTHALMOLOGIE," *(By Dr. Tscherning).*

The great stumbling block in lenses with two foci is the question of centreing, ... it is necessary that each part of the lens should be correctly centred. . . . . The problem has been solved by a method invented . . . . in this manner the defect of centreing is completely overcome. It is this method which is employed by the Uni-Bifocal Company, of London.

275

293 Set of trial bridges

+ 2.50 sph

+ 1.0 cyl 180 = +1
+ 1.0 cyl 90

- 1.0 cyl 90