REFRACTION

AND

MOTILITY OF THE EYE

WITH CHAPTERS ON COLOR BLINDNESS
AND THE FIELD OF VISION

DESIGNED FOR STUDENTS AND PRACTITIONERS

BY

ELLICE M. ALGER, M.D., F.A.C.S.
PROFESSOR OF OPHTHALMOLOGY AT THE NEW YORK POST-GRADUATE MEDICAL SCHOOL, ETC.

WITH ONE HUNDRED AND TWENTY-FIVE ILLUSTRATIONS

SECOND REVISED EDITION

PHILADELPHIA
F. A. DAVIS COMPANY, PUBLISHERS
ENGLISH DEPOT
STANLEY PHILLIPS, LONDON
1920

PRESS OF
F. A. DAVIS COMPANY
PHILADELPHIA, U.S.A.

PREFACE TO SECOND EDITION.

This little book has been reprinted a number of times without change since its first appearance, but the recent remarkable recrudescence of interest in Ophthalmology has made another edition desirable, with some changes and additions.

Prepared originally as a series of lectures to the writer's post-graduate students it included a number of topics not usually found in books on refraction. Every effort was made to avoid the theoretical without sacrificing the essential; to have each subject prepare for and lead up to the following one; to avoid the laying down of dogmatic rules, but to explain reasons so that the student should eventually rely on himself and be prepared to undertake the entire functional examination of the eye.

The common belief that Refraction is nearer an exact science than any other department of medicine has been a great misfortune to Ophthalmology. On this postulate men with equal training should arrive at exactly the same results. It leads many ophthalmologists to consider refraction as professional drudgery, as uninteresting as the measurement of the schematic eye, except for the fee involved; and is the chief basis for the lay belief that it is not essentially a department of medicine at all.

Refraction is more than a science. It is an art based on a science, and the pre-eminent scientist may notoriously be a very poor artist.

Theoretically there are few eyes that could not be "glassed." But if the physician believes that glasses are a nuisance which, like drugs, should only be prescribed when clearly indicated; if he considers not the eyes alone but the whole patient and finally prescribes what he thinks that patient needs, whether it be simply ocular hygiene, or glasses, or an operation; if he then instead of washing his hands of the result like a mere scientist, watches it sympathetically and hopefully, he converts what might be drudgery into service and earns some of the proverbial joy of the artist.

E. M. A.

INTRODUCTION.

The preparation of this work is the result of several years of post-graduate teaching, and while portions of it may be of interest to those who are already competent ophthalmologists, it is especially designed to meet what the writer conceives to be the needs of two individuals, the general practitioner and the embryo ophthalmologist.

Whatever may be our personal estimate of the permanent value of writings such as those of Gould, Stevens, Ranney and others, we must all admit that they have worked a great change in the popular idea, whether lay or professional, of the scope of ophthalmology. The physician has always been ready to admit the value of fundus examinations in occasional cases of nephritis, meningitis and the like, but these occasions were so rare that he has thought best to devote his attention to diagnostic methods of wider application. He has always been ready to admit the necessity of glasses to those who could not see but, as he had neither the time nor the skill to provide them, he neglected the subject entirely. But of recent years a great change has taken place. A few men have long taught, almost unheeded by the profession, that the relation between the eyes and other organs is so intimate, that defects in one often result in functional defects in the others. The laity first viewed the idea with incredulity, later with increased favor. Very possibly they will let their enthusiasm carry them too far, and lead them to expect too much, but at present there is a public demand so large and so profitable, that it has attracted the attention of irregulars of all sorts as the advertising pages of every magazine will show.

The physician is being compelled to investigate that he may meet the inquiries of his own patients, and even if he has no time or desire to enter the special field himself, he must have an intelligent conception of the possible rôle of the eyes in a given case.

The limits of the field are not yet clearly defined: probably they will expand in some directions and contract in others, but they overlap more or less nearly every department of medicine. The pediatrist is beginning to understand that defective eyes are responsible for much of the mental hebetude of children, for truancy and dislike for the mental tasks which are normally attractive to the young, for headaches, habit spasms, and possibly for some epilepsies as well. The internist is coming to recognize that malfunction of the eyes may at times cause some of those vague conditions which it used to be the fashion to call vertigo, biliousness, and malaria and more recently uricacidemia, autotoxemia, and the like; for many cases of functional neurosis of the stomach, the heart, the intestines. The neurologist must admit the eyes as a factor of importance in many cases of headache, insomnia, and those persistent and discouraging states of mental and physical irritability or depression which he calls neurasthenia. The gynecologist is beginning to recognize that many of the headaches and nervous manifestations usually ascribed to the menopause are due rather to the simultaneous onset of presbyopia and are relievable by glasses.

But we shall never know the exact limits of the field, except by a vast amount of more or less experimental collaboration between general practitioners and specialists, and if we expect to secure this collaboration we must give in return results based on work that is both honest and skillful. In the first respect I do not doubt we can meet the demand but no one who makes a practice of investigating the previous treatment of his new patients can avoid the conclusion that the general average of work is very far from what it should be.

The reason for this is the almost universal lack of systematic instruction. The embryo specialist has too often with the lapse of years become very rusty in his physics, anatomy, and physiology. When he begins his post-graduate work in one of the large cities he is invariably impatient of the preliminary drudgery which he ought to have mastered at home, and, fascinated by the variety of instruments and the facility with which others use them, he is apt to forget that the making of a good ophthalmologist requires much more than the possession of a complete office.

The man who neglects the fundamentals in his eagerness to work on patients, and to see and do operations, rarely acquires more than a smattering of his subject.

By mastering the principles at home, one subject at a time, with a few simple instruments and a schematic eye, the student when he finally comes to his post-graduate work will be surprised at the ease with which he takes it up. He not only derives many times more benefit from his instructors but actually saves much time.

There are two great classes of patients who consult the physician regarding their eyes: the first need glasses simply to improve their sight, while the second come to be relieved of headaches or reflex troubles of some kind. Though it requires a larger outfit, the task is in the first class often absurdly simple, and since the practitioner will certainly have more skill than the itinerant optician or department store clerk to whom most of these people now resort, he may without hesitation attempt their correction. The relief of the second class often demands an exactness of correction which is apparently beyond the reach of many professed ophthalmologists, and certainly should not be attempted by the general practitioner if other help is available. Even if he makes no attempt to correct personally the errors he discovers, he can often throw light on a puzzling case and perhaps bring new hope to some miserable sufferer.

In conclusion the writer wishes to acknowledge his obligation to text-books such as those of Ganot, Foster, Fuchs and Ball, and to the special works of many others. It may seem an impossible task to harmonize the views of such diverse authorities as Gould, Stevens, Savage, Duane and Valk, but the writer can at least acknowledge his deep obligation to every one of them. From the last-named in particular he has derived through the personal contact of many years not only instruction and advice but the stimulating influence of an inquiring mind and a perennial enthusiasm.

E. M. A.

CONTENTS.

CHAPTER XVIII.

Refraction and Motility of the Eye.

CHAPTER I.

OPTICS.

Light may be defined as that form of energy which, by its stimulation of the retina, excites the sensation of vision. Every luminous body emits light. The older corpuscular or emission theory of light taught that infinitesimal particles were given off by such bodies which traveled with infinite velocity. The more modern undulatory theory presupposes an agitation of the luminiferous ether which travels in all directions from its source in the form of oscillations or waves.

On the emission theory the particles were supposed to be in actual motion, like bullets discharged from a gun, while on the undulatory theory there is no actual motion of the particles themselves, but only a state of disturbance which manifests itself by a series of waves with transverse vibrations like those caused by striking a stretched wire. In the illustration (Fig. 1) the straight lines show the direction in which the rays of light travel from a luminous body, while the curved lines show the manner of progress. These waves may have different heights and lengths, and produce varying sensations in proportion to these, but always travel in straight lines, so long as the medium is of a constant density.

A *ray* of light may be defined as the smallest conceivable portion of light. Rays of light starting from their source and proceeding in all directions must necessarily be more or less divergent, but it is evident that rays coming in the same general direction from a source infinitely distant will diverge so little that they may be considered as parallel, and for our purposes rays from a source twenty feet distant may be considered practically parallel. A *pencil* of light consists of a number of rays practically

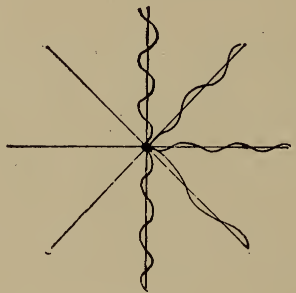


FIG. 1.

parallel to a central ray, while a *beam* of light is simply a larger collection of parallel rays. Though rays of light always travel in straight lines while in a homogeneous medium, they cease to do so when the medium changes, and undergo *reflection, refraction, absorption* and *dispersion,* the amount of each depending on the nature of the new medium.

When rays of light are *absorbed,* they cease for the time to exist as light, but are transformed into heat, or may be given off again in the form of fluorescence or of phosphorescence. Absorption of light is generally associated with reflection. Appreciation of color is due to the absorption by the object viewed of all the light except those rays which, when reflected or transmitted, excite in the retina the sensation of some definite color. Thus, a red glass absorbs all the light except the red rays.

The *dispersion* of light does not concern us especially. It is sufficient to say that it is by the scattered rays of light that non-luminous objects are visible, and it is due to the reflection of rays from very irregular surfaces.

Reflection is inseparable from refraction. If an object were so absolutely transparent that all rays of light passed through it, it would be invisible. Plate glass is perhaps the nearest approach to perfect transparency, and yet many rays are reflected from the most perfect of plates.

When a ray of light impinges on a surface, the angle which it makes with a perpendicular to this surface is the angle of incidence, while the angle it makes in passing away is the angle of reflection.

The angles of incidence and reflection are always equal, and the incident and reflected rays are always in a plane perpendicular to the reflecting surface. The two laws may be demonstrated by the apparatus represented in Fig. 2. It consists of a graduated circle in a vertical plane. Two brass slides move around the circumference, on one of which is a ground glass screen, *P*, and on the other an opaque screen, *N*, with a small central opening. Fixed to the latter is a small mirror, which can be adjusted, but is always in a plane perpendicular to the plane of the graduated circle. At the centre of the circle a small plane mirror is placed horizontally, *O*.

A pencil of sunlight is reflected by the mirror through the aperture *N* so as to fall upon the mirror *O*, whence it is reflected and caught on the screen *P*, which is moved to the necessary position. The number of degrees in the arc *AN* will be found equal to those in *AP*. Therefore, the angle of incidence, *AON*, must be equal the angle of reflection, *AOP*, and since the plane of the circle is perpendicular to the plane of the mirror *O* by construction, the plane of the rays must also be perpendicular to it. This can be proven to be true for any other position of *N*, which causes a corresponding change in the

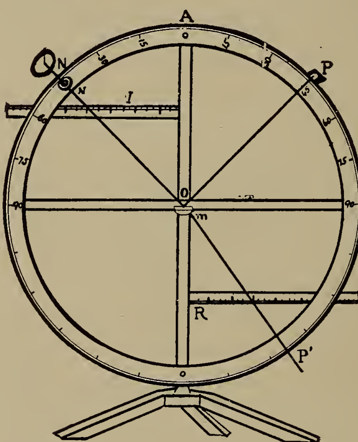


FIG. 2.

position of *P*. If the source of light, *N*, is moved to *A* perpendicular to *O*, the screen, *P*, would have to be moved to the same spot to intercept the reflection. Consequently, when light is reflected back to its source, its path must be exactly perpendicular to the reflecting surface at the point of reflection.

Fig. 3 shows two rays of light from a common source reflected from points *C* and *D* of a plane surface. The angles *aCA* and *a′CA*, being the angles of incidence and reflection of one ray, must be equal. Similarly *aDB* and *a″DB* must be equal. Then the angles *aCA* and *aDB* of incidence, must have the same relation to each other as the angles of reflection which are their exact equivalents. Therefore, rays from a common source after reflection from a plane surface are equally divergent after reflection. By

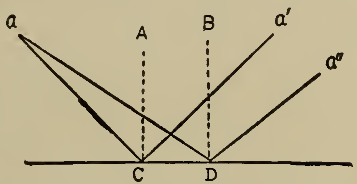


FIG. 3.

supposing that rays from *a′* and *a″* are convergent, we can show that they are equally convergent after reflection, and the case is easier still if we suppose parallel rays, since the angles would all be equal.

Let *MN* represent a plane mirror on which rays of light from the object, *AB*, are reflected to the eye. Rays

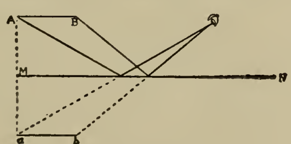


FIG. 4.

from *A* appear to come from *a*, while rays from *B* appear to come from *b*. Therefore, the object, *AB*, appears to be situated at *ab*, behind the mirror, and it can easily be proven to be as far behind *MN* as the object actually is in front of it. Such an image is called a virtual one.

Since the distance of objects from the eye is estimated with the aid of experience by the angle which rays coming from them to the eye make with each other, which is unchanged by plane mirrors (see "Visual Angle"), the apparent distance of AB from the eye is equal to the sum of the incident and reflected rays. The case is very different, however, if the reflecting surface is a rough one. If we substitute in Fig. 4 a lamp for the object and a printed page for the mirror the rays, striking the page undergo the *irregular reflection* or dispersion alluded to before. We get no image of the lamp but the page becomes itself a source of light from which rays emanate and enter the eye as though they came from MN. The page remains visible so long as light falls upon it no matter what change is made in the position of the lamp. On this principle we illuminate the fundus of the eye by a mirror and its details become visible, and since the illuminated area acts as a source of light we can estimate the refraction by tracing the course of the emergent rays, disregarding entirely the course of the entering ones.

The appearance of images in a mirror of objects which we are accustomed to consider as having a right and left side is changed. For instance, in the reflection of a person in a plane mirror the right side of the body is reflected in the right side of the mirror, but as the image appears to face the observer, a motion of the right hand will appear in the mirror like a corresponding motion of the left hand on the part of the reflection. The same thing occurs in the reflection of letters on a page or test card. This is known as *lateral inversion.*

Reflections from CONCAVE MIRRORS are based on exactly the same laws of the equality of the angles of incidence and reflection (Fig. 5).

If MN represents such a concave mirror, with parallel rays of light impinging on it, and C the centre of curvature, the ray, *CF,* passing through the centre of curvature must be perpendicular to *MN* and will be reflected back from *F,* the vertex or middle of the mirror. *CF* is then the *principal axis* of the mirror, while any other rays passing through *C* must also be perpendicular to the mirror at the point of intersection and constitute *secondary axes.* Rays parallel to the principal axis after reflection will intersect the principal axis at *O,* the angles of incidence and reflection being equal. The other parallel rays will intersect the principal axis at the same point which is known as the *focus* of the mirror, and its distance from *F* as the *focal*

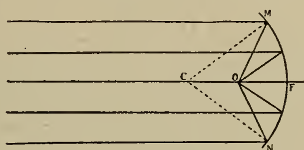


FIG. 5.

length. The focal length of weak concave mirrors is approximately half the radius of the curvature.

Rays of light from infinity are parallel and after reflection will all pass through the focus, and, conversely, rays emanating from its focus will after reflection emerge parallel. As the source of rays approaches the mirror, the rays become more divergent and come to a focus nearer and nearer to the centre of curvature; when the rays emanate from the centre of curvature, being perpendicular, they are all reflected back to their source. When the light is between *C* and *O,* the rays cut the principal axis further and further from the mirror, till it reaches *O,* when they become parallel, and as the light is carried still nearer the mirror, the rays become divergent and their focus a virtual one formed behind the mirror by projection of the rays.

Hitherto it has been supposed that the luminous object placed in front of a mirror was simply a point, but if the object is larger we can imagine it as composed of a number of points, each on a secondary axis, and by locating the focus of each we should determine the position of the *image* of the object.

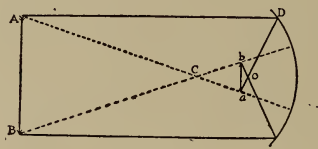


FIG. 6.

The reflection of *AB* in a concave mirror is constructed thus. A ray, *AD,* parallel to the principal axis of the mirror, is reflected so as to pass through the principal focus, and the point where it meets the secondary axis, drawn from *A,* through the centre of curvature, *C,* will be the point where the image of *A* is formed, namely, *a.* In a similar way we locate the image of *B* at *b,* then all the imaginary points between *A* and *B* will be reflected so as to fall between *a* and *b.*

This image may be seen in two ways, either by placing the eye at *ab,* or it may be intercepted on a screen at the same place; therefore the image is real, inverted, smaller and placed between the centre of curvature and the principal focus. If we place the object at *ab* between the centre of curvature and the focus, the image will be at *AB,* larger, inverted and real. If the object is placed at the focus, no image is formed, since the rays after reflection will be parallel to the principal axis.

If the object is at *AB* (Fig. 7) within the focus, the reflection of *A* will occur at *D* and that of *B* at *E.* Consequently, the only place where the secondary axes, *CA* and *CB,* can intersect these lines is behind the mirror at *a* and *b,* which represent the extremities of the image. This image is then *virtual* in that it cannot be projected on a screen, it is larger than the object and is erect.

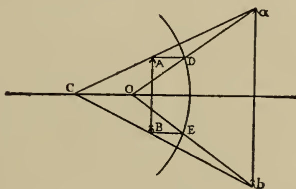


FIG. 7.

If the mirror be a convex one, the rays are divergent, no matter how near or how far *AB* is from the mirror. Consequently, the only points where these rays could intersect the secondary axes, *AC* and *BC,* is at the two points behind the mirror, which determine the position of the

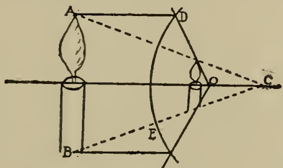


FIG. 8.

image. Consequently, the reflection in a convex mirror is always erect, small and virtual.

Refraction.—When rays of light pass from one medium to another of different density, they are refracted or bent.

A very good illustration of refraction is the apparent bending of a cane thrust obliquely into a pool of water.

Let *A, B* and *C* represent three silver coins, so arranged on the bottom of an empty pail, that the light from the candle reflected from *B* comes to the eye of the observer and makes it visible. The other coins are invisible, because one (*A*) receives no light from the candle and the other (*C*) is hidden behind the edge of the pail. But if the pail be filled with water all three coins at once become visible. If the sides of the pail be considered as perpendicular, we see at once that the rays from the candle passing from the air into a denser medium have been

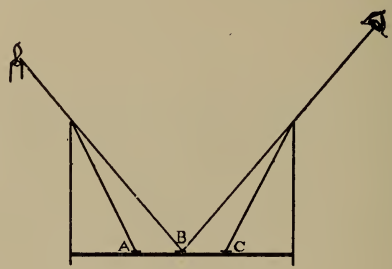


FIG. 9.

refracted or bent toward the perpendicular so as to illuminate the coin, *A*. On the other side of the pail we see that the rays reflected from the coin, *C*, when they pass from the the water into a medium of lesser density, have become bent from the perpendicular so as to reach the eye of the observer. We shall find this true in the case of other media than air and water, and the greater the difference in their density, the greater the refraction, and the law of refraction can be stated thus. *When a ray of light passes from one medium to another of different density in a direction perpendicular to the surfaces, it is not refracted; when its course is not perpendicular, it is bent toward the* *perpendicular in the denser medium and away from it in the lighter medium.* The amount of refraction between two media is always the same and in the same plane, as can be demonstrated by a modification of the apparatus used in showing the law of reflection. (See Fig. 2.)

The plane mirror in the centre of the graduated circle is replaced by a semi-cylindrical glass vessel of water at the exact centre of the circle. The pencil of light from *N* is refracted on passing into the water at *O*, but passes out without refraction, because its direction is perpendicular to the curved bottom of the glass vessel. The screen, *P*, is moved along the arc till it intercepts the pencil at *P'*.

A line, *I*, at right angles to *AO*, meeting the incident ray is known as the sine of the angle of incidence *AON*, while a similar line, *R*, is the sine of the angle of refraction, *ROP'*. The length of these sines can be read off on two graduated rules movable so as to be always horizontal, and while these lengths will vary with the size of the angles, they always maintain an exact proportion. For instance, a ray passing from air into water, the sine of the angle of incidence will be to the sine of the angle of refraction, as 4 is to 3, while if the ray were traveling in the reverse direction, the proportion would be 3 to 4. This is known as the *index of refraction* and varies between different media. That of air to glass is 3/2 or 1.5.

When a luminous ray passes from one medium into another of less density, as from water into air, the angle of incidence is always less than the angle of refraction. It therefore follows that there must be one angle of incidence of such value that the emergent ray would be exactly parallel to the surface at *OR* and rays, as from *P*, making a greater angle would not emerge at all, but be reflected at the surface toward *Q* (Fig. 10). This angle beyond which total reflection occurs is known as the *critical angle,* and as there is no loss of light from absorption or transmission, the reflection is the most brilliant possible, and therefore this

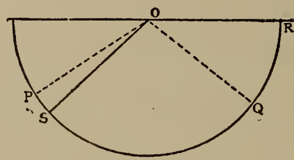


FIG. 10.

method is frequently used in optical instruments. The critical angle from water to air is 48° 35′, and that from glass to air 41° 48′.

When a ray of light passing through the air impinges on a medium with greater density but with two surfaces, the same rule holds good.

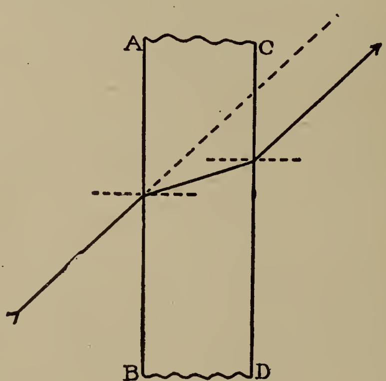


FIG. 11.

Let *ABCD* represent a section of plate glass with parallel sides. A ray of light striking perpendicularly will pass through without refraction, while if it strikes obliquely it is bent toward the perpendicular when it enters the glass, and again from the perpendicular when it leaves, and since the surfaces of the glass are parallel, the ray passes on in a course exactly parallel to its former one. When the glass is a thin one, the amount of displacement is so slight that it is commonly ignored.

If, however, the sides of the glass are not parallel, but approach each other, we have what is called a *Prism*, the angle of the sides being known as the angle of the prism.

Let *AB* and *BC* represent the sides of a prism of glass,

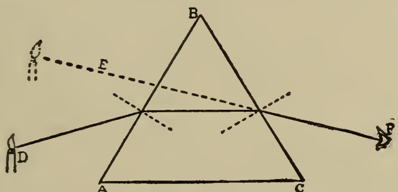


FIG. 12.

AC being the base of the prism and *B* the apex. The angle *ABC* is known as the *refracting angle* of the prism. A ray of light from a candle, *D*, impinging on the side *AB*, is refracted toward the perpendicular, and when it passes through the side *BC* into a lighter medium is again refracted, this time away from the perpendicular. If the ray enters perpendicular to either surface of the prism, the refraction all takes place at the other and is the greatest possible. If the ray passes in such a direction that its course is parallel to the base, the angles of incidence and emergence are equal and the total refraction is the least possible. The light from the candle D is bent, so as to come to the observer at *F* and appears to him to come from *E*. *A prism therefore bends rays of light toward its base* *and causes an apparent displacement of the object toward the apex.*

The refracting power of a prism is directly in proportion to the refracting angle of the prism. The total deviation is measured by the angle formed by the direction of the incident and emergent rays, and in prisms of ten degrees is equal to half the angle of the prism, but in stronger prisms the angle of deviation increases.

Prisms whose principal section is an isosceles right angled triangle afford a good example of *total reflection.*

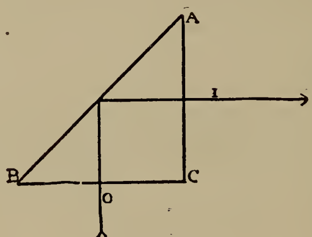


FIG. 13.

In such a prism, *ABC,* a ray of light, *O,* which enters perpendicular without refraction and makes with the face, *AB,* an angle equal to *B,* or 45°. But, since the critical angle for glass is 41°45′, it cannot emerge, but undergoes total reflection and emerges in the direction *I,* perpendicular to *AC.*

In order that any ray refracted by the first face of a prism may emerge from the second, the refractive angle of the prism must be less than twice the critical angle of the prism substance. In glass, therefore, whose critical angle is 41°48′, objects cannot be seen through a prism greater than 82°96′, or less than a right angle.

Prisms were formerly numbered in degrees according to the refracting angle made at the intersection of their surfaces, but, as two prisms with exactly the same refracting angle might be of dissimilar strength owing to a difference of density in the glass, two other methods have been proposed by which the number of the prism depends on its power of deflecting the rays of light.

METHOD OF DENNETT.—If we take a circle of any diameter and mark off on its circumference a distance exactly equal to its radius of curvature, this will always represent an angle of 57.295 degrees and is called the arc of the radian. A prism base down at the centre of curvature which will deflect a ray of light downward exactly $^1/_{100}$ part of the arc of the radian is called a *centrad,* designated by a small triangle, base up ▽. The centrad then causes the deflection of rays of light .57295° or approximately half a degree.

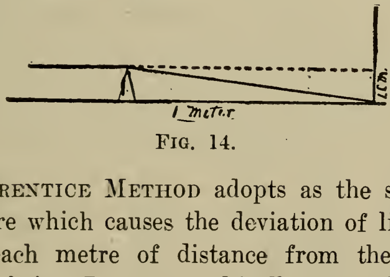


FIG. 14.

THE PRENTICE METHOD adopts as the standard the prism dioptre which causes the deviation of light 1 centimetre for each metre of distance from the prism, the abbreviation being *PD,* or graphically △. This is a very convenient method for use in the consulting room. For instance, a prism of 5 △ strength would deflect rays of light 5 cm. at one metre, 10 cm. at two metres and 30 cm. at six metres, which is the usual working distance.

For practical purposes it makes no difference which scale is used in one's trial case, since the three systems are almost exactly equivalent up to 20°, while the centrad and prism dioptre, which are almost universally used, do not vary materially up to 35° or 40°.

Neutralizing Prisms.—To find the strength of an unknown prism one should look through it at a line at any convenient distance, thus:

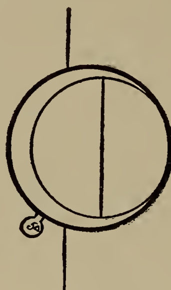


Fig. 15.

Since prisms cause an apparent displacement of objects toward their apices, the edge of the glass on the right must be the apex of the prism. If, then, we place over this prism others of known strength, with the base of one over the apex of the other till the line looked at is again continuous, the two prisms must be of exactly equal strength; or we can view through the prism a series of

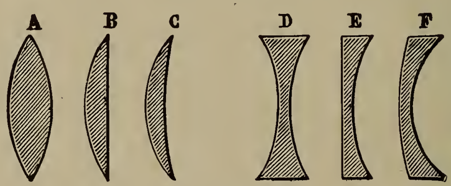


Fig. 16.

parallel lines one centimetre apart and one metre distant. Each space of displacement of the first strong line indicates one prism dioptre. Such a "prismometre scale" can be calculated for any convenient distance.

Lenses.—A lens is a portion of transparent substance having one or both surfaces curved. Lenses are commonly considered as being made of glass, but it is not necessarily so. A bead of perspiration, for instance, forms a diminutive, but powerful, lens for collecting the sun's rays.

SPHERICAL LENSES are so called because one or both surfaces are curved like sections of a sphere and may be either convex or concave.

Every convex lens may be considered as being made up of an infinite number of prisms with their bases toward the centre of the lens.

Consider in Fig. 17 such a lens in which each half has three of its component prisms indicated with an infinite number of imaginary prisms occupying the intervening intervals.

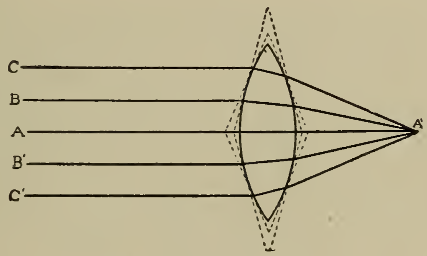


FIG. 17.

The ray of light from A striking perpendicularly on both surfaces of the lens passes through without refraction to A'. The rays from B and B', parallel to A, impinge on the first prism of which the sides are almost parallel and are bent toward the bases of the prisms or the centre of the lens and are again bent slightly on passing out on the other side so that both unite with the original ray at A'.

The rays C and C' impinge on prisms which are further from the centre and consequently stronger, and the refraction is greater and the rays join the others at A'.

In a convex spherical lens then a ray of light *AA'* which is perpendicular to both surfaces is called the *axial ray* and passes through without refraction, while rays parallel to the axial ray are bent more and more strongly toward the axial ray, as they are more and more distant from it, till they all come together at a point on the axial ray, called the *focus* of the lens.

In very thick lenses the rays of light which pass through the periphery are refracted much more than the central ones so that they come to a focus inside the actual focus. This is known as spherical aberration, but in the thin lenses used in ophthalmology it is so slight as to be negligible.

When an object is viewed through a convex spherical lens as the lens is moved in one direction the object appears to move in the opposite. The lens being made up of prisms with their bases toward the centre, all objects except those seen through the exact centre seem displaced toward the edge of the glass, and the prismatic action being progressively stronger, the displacement becomes greater and greater as the object is seen through the periphery. The stronger the lens, the more rapid is the "against" motion of an object viewed through it.

If we suppose a convex lens of considerable thickness, the ray which strikes both surfaces perpendicularly passes through without refraction. This ray, *AF,* is the axial ray and its path the *principal axis,* and the point on the principal axis where the parallel rays come together is the *principal focus F.* Other rays which strike one surface obliquely if they enter and emerge from points whose tangents are parallel to each other, undergo exactly the same displacements as in passing obliquely through a window glass. They are refracted toward the perpendicular on entering, and away from it on emerging, and pass on in a course exactly parallel to the first one. There are two points on the axial ray so situated that oblique rays directed toward one will appear to come from the other after lateral

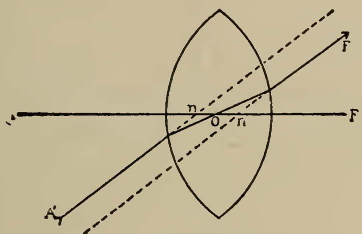


FIG. 18.

displacement. These points, *nn,* are known as *nodal points* of the lens; the paths of the rays directed toward the nodal points are known as the *secondary axes, A′F′;* and the point where the secondary axes cut the principal axis is the *optical centre* of the lens, *O*. Every lens has two nodal points and an optical centre, but in the thin lenses of ophthalmology the nodal points are practically coincident

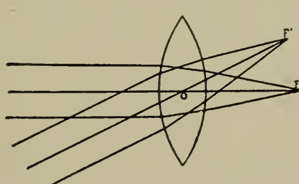


FIG. 19.

and constitute the optical centre, so that it is practically true that all rays that pass through the optical centre, aside from the principal axis, constitute secondary axes and are not refracted, while all rays parallel to a secondary axis come to a focus on it after emergence, such foci being called *secondary foci* (Fig. 19).

The distance between the optic centre of a lens and its focus, is the *focal length* of the lens and is the chief means of indicating its strength. If a given lens brings parallel rays of light to a focus at a given point, a candle placed at that point, *C*, will send out rays which, passing through, emerge parallel. If the candle is brought nearer the lens, the rays must emerge divergent, while if the candle is carried beyond the focus of the lens, the rays will emerge convergent and come to a focus on the principal axis.

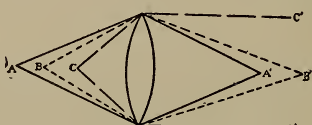


FIG. 20.

These two foci *A* and *A'*, *B* and *B'*, are called *conjugate foci* from the fact that rays emerging from one will invariably come to a focus at the other, and as one conjugate focus approaches the lens on one side, the other recedes toward infinity. When one conjugate focus is just twice the focal length away from the optical centre, its fellow will be an exactly equal distance away on the other side.

This applies not only to the principal axis, but also to the secondary axis, each focus of which has its conjugate. This enables us to understand the construction of images.

Images From Convex Lenses.—Let *AB* represent a candle at any convenient distance from the lens. Rays from the point *A* passing through the optical centre continue without refraction, while other rays from the same point passing through other parts of the lens intersect the axial ray at *A'*, which is the conjugate focus of *A*. In the same way the conjugate focus of B is at B'. The infinite number of focal points on the candle between A and B have their corresponding conjugates between A' and B' and an image of the candle is formed there which is real in the sense that it will be visible if a screen be placed at that

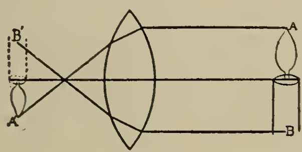


FIG. 21.

point. It is also inverted and much smaller than the original. If the candle is approached toward the lens, the image formed on the other side recedes, at the same time growing larger, but it is still inverted and real. But when the candle is placed so that it is within the principal focus of the lens, the rays of light becoming more and more divergent form no focus.

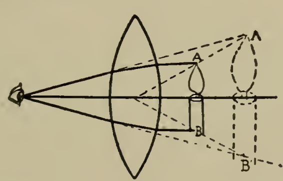


FIG. 22.

If AB represent the object, rays from A through the optic centre are unrefracted, but the other rays from A through the periphery of the lens are not refracted enough to intersect the axial ray AC and are divergent, the only meeting place being by their projection backward to A'. Rays from B are also divergent and only meet at B'. The image $A'B'$ then is on the same side of the lens as the object, is larger than the object and is erect. Such an image which is formed by the prolongation backward of the divergent rays is called a *virtual image* and cannot be projected on a screen, but is visible to the eye when looking through the lens.

The relative sizes of images and objects is in proportion to their distance from the optical centre of the lens.

Concave Lenses may be considered as being made up of an infinite number of prisms with their bases outward. The ray of light, *AFA'*, which passes perpendicularly

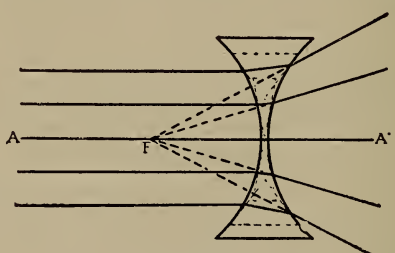


Fig. 23.

through the optical centre of the lens, is the axial ray and is unrefracted, while all rays parallel to the axial ray are bent outward increasingly as they are nearer to the periphery of the lens. Since parallel rays are divergent after refraction through a concave lens, they do not meet to form a positive or real focus, but by being projected backward toward their source as in Fig. 23, they form an imaginary or negative or virtual focus, *F*.

Conjugate foci are formed by concave lenses by projection backward so that they are always virtual and on the same side of the lens. The secondary axes are those formed by rays passing through the optic centre without being perpendicular or normal to the lens. They pass through as in convex lenses with a slight lateral displacement which is commonly disregarded, while rays parallel to the secondary axes emerge divergent. The conjugate foci on the secondary axes, as on the principal axis, are on the same side of the lens and are virtual.

Images formed by concave lenses.—If *AB* represents an object at any given distance from a concave lens, *C* being the optic centre, all rays from *A*, except those passing through *C*, are refracted and emerge divergent, and, if projected, form a virtual focus at *A′*. Rays from *B* undergo

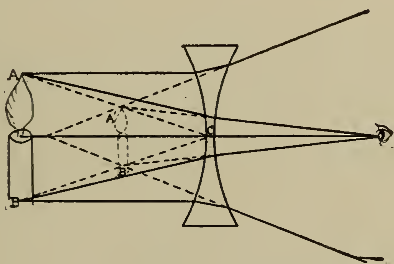


Fig. 24.

a corresponding change and form a virtual conjugate focus at *B′*, while rays from the intermediate points between *A* and *B* form foci between *A′* and *B′*. Therefore the object *AB* forms an image at *A′B′*, which is a virtual image and cannot be projected on a screen and is always on the same side as the object, erect and smaller. Such an image can be seen by the eye as in the figure. It must be remembered that all the rays from *AB*, no matter what part of the lens they strike, form the virtual foci at *A′* and *B′* but that most of these are so divergent as to entirely miss the eye which is conscious of only the ones near the centre of the lens. Rays from *A*, which reach the eye after refraction, appear to come from A', and those from B appear to come from B'. Therefore, the observer looking through a concave glass sees an image which is always erect and smaller than the object, and the further the object, the smaller the image. A concave glass is, then, always a minifying glass.

Since a concave lens is made up of prisms with the base out, when the lens is moved from side to side, all objects seen through it are apparently displaced toward the centre of the lens, and, therefore, appear to move in the same direction as the lens, and the stronger the lens the greater the motion.

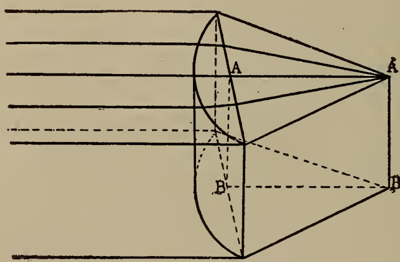


FIG. 25.

CYLINDRICAL LENSES, usually called cylinders (abbreviation, cyl.), are sections cut from a cylinder parallel with its axis, and are either convex or concave.

The figure represents a convex cylinder about the axis, AB, which is vertical. A ray of light which strikes perpendicularly so as to pass through the axis, A, is not refracted, but passes on through A'. All other rays which are parallel to AA' in the vertical plane also pass through without refraction and pass, still parallel, through the line $A'B'$. All the rays parallel to AA' in the horizontal meridian are refracted toward AA' and come to a focus at A'. Similarly all the parallel rays in the infinite number of horizontal planes between A and B are refracted toward their own axial ray and come to a focus at corresponding points on $A'B'$. Evidently then a convex cylinder refracts only rays of light in the meridian at right angles to its own axial plane, and its focus, instead of being a point as in a spherical lens, is a line parallel to its axis. If the rays come from a point of light at an infinite distance, the rays passing through the vertical plane would be parallel and the line $A'B'$ would exactly equal in length AB, and the distance from the optical centre of any horizontal section, say that of A and A', would be the focal length of the cylinder; if the light approached, the rays of light would be divergent; those in the plane of the axis would emerge unchanged, while those at right angles to the axial plane would be less and less convergent. Consequently, the image line $A'B'$ would tend to become longer and more distant, till it approached infinity, but still a real image.

When the point of light is at a distance equal to the focal length of the lens, the rays in the axial plane would be very divergent, while those at right angles would emerge parallel after refraction; consequently no image would be formed. When the light is approached within the focal length of the cylinder, rays of light would be divergent in both planes and the focal line would be formed by projection. The image then would be a line on the same side as the object, in other words a virtual instead of a real one.

Any object looked at through a convex cylinder is unchanged in the diameter corresponding to the axis of the cylinder and magnified in the meridian at right angles. For instance, if a small circle be viewed through a cylinder with the axis vertical, its vertical diameter appears unchanged, while its horizontal one is increased, making it appear oval. A convex cylinder may be said to consist of prisms with their bases toward the axial plane and increasing in strength toward the periphery. Consequently, if in viewing a fixed object through it, the cylinder be moved up and down in the line of its axis where there is no refraction, the object seems stationary, while if the cylinder be moved from side to side, the object is projected toward the apices of the prism and appears to move in the opposite direction to the movement of the cylinder, and the stronger the cylinder the more rapid the motion.

Furthermore, if a line be viewed through the cylinder

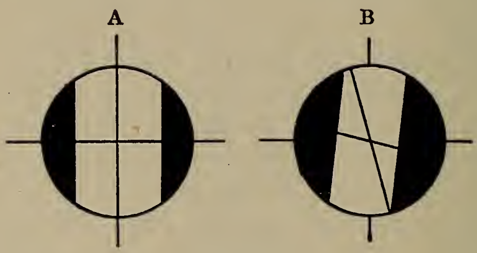


FIG. 26.

held in such a position that the line coincides in direction with the axis of the cylinder, the portion of the line seen through the cylinder will appear continuous with that seen outside the cylinder, as will a line at right angles with the first line.

But if the cylinder be rotated slightly wheel-fashion to the right, the upper portion of the vertical line above the centre appears displaced toward the thinner edge of the cylinder through which it is seen, while the lower half of the line appears displaced in the direction of the other edge, through which it is visible.

When crossed lines at right angles are viewed as in the above figure, the horizontal line also appears displaced toward the thinnest part of the cylinder. In all these displacement tests with convex lenses, whether spherical or cylindrical, they should be held reasonably close to the eye, since otherwise, if they are strong and the object viewed is distant, the rays will cross before reaching the eye forming at their junction an aërial image which moves in the opposite direction.

A Concave Cylinder is one which is thickest on the edges and thinnest at the centre, and may be considered as made up of prisms with their bases outward.

Rays of light from a point of light at infinity, when they coincide with the axis of the cylinder, are not refracted, while those in all the planes at right angles to the axis emerge divergent. Their focus as in the concave spherical lens is found by projecting them back to their point of junction. The focus of the concave cylinder is a negative one, and no matter how close the light is brought to the lens, the rays emerge divergent, and the image formed is a virtual one. When seen through such a lens, an object appears to have its size unchanged in the diameter corresponding to the axis, while the diameter at right angles seems smaller. A circle viewed through a concave cylinder with the axis vertical appears oval, because its transverse diameter is lessened. When an object is viewed through a concave cylinder moved in the direction of its axis, the object remains stationary, but if the cylinder is moved from side to side at right angles to the axis, since it is composed of hypothetical prisms with the bases out, the object is displaced toward the centre and seems to move in the same direction in which the cylinder is moving, the rapidity indicating the strength of the cylinder.

If two lines crossing each other at right angles are viewed through a concave cylinder held in such a way that one of the lines coincides with the axis of the cylinder, the position of both lines seen through the glass is continuous with the portions outside the glass. If now the cylinder be rotated slightly wheel-fashion to the right, the upper half of the line is displaced toward the axis of the glass and appears carried to the right, while the lower half is also displaced toward the axis and is carried to the left an equal amount. Consequently, the portion of line seen through the glass seems to rotate on its centre as a pivot in the same direction in which the cylinder is being rotated. For the same reason the line at right angles to the axis tends to keep its extremities in line with the thinnest edge of the glass and appears to rotate in the opposite direction, the amount of torsion being in direct proportion to the strength of the lens.

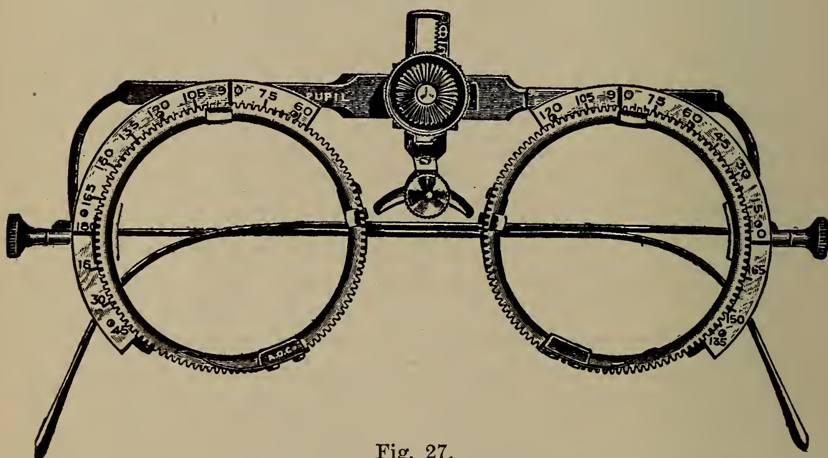


Fig. 27.

The cylinders used in the trial case commonly have the axis indicated by a mark at each end and many have the edges ground parallel to the axis as shown in Fig. 26. The position of the cylinder before the eye is described by its relation to the horizontal and vertical planes of the head. For this purpose the cells in the trial frame are graduated in degrees, beginning at the (observer's) right of each cell. A cylinder whose axis was horizontal would be recorded as being at the axis, 0, or more commonly 180. A vertical axis would be axis 90, while all the intermediate positions possible can likewise be indicated in degrees.

Less commonly trial frames are numbered from the vertical meridian which is marked *O* and the degrees marked up to 90 on both sides.

Cylinder axis vertical is equivalent to axis 90 on the other scale, and, if the axis is inclined inward or outward, it is indicated 15° nasal or temporal, as the case may be.

NUMBERING OF LENSES.—Lenses are numbered according to their focal lengths and it was formerly the custom to express this distance in inches. For instance, a convex lens which would bring parallel rays of light to a focus at 1 inch from its optic centre was the standard of comparison and called an inch lens. A lens which had a focal length of two inches, being only half as strong as the standard, was numbered $\frac{1}{2}$. A four-inch lens was expressed as having $\frac{1}{4}$ the power of the unit and so on, the denominator of the fraction indicating the focal length of the lens in inches. The disadvantages of the system were first that the inch varies materially in different countries, and second, the inconvenience of expressing combinations most commonly used, as for instance, $+\frac{1}{60}+\frac{1}{72}$. The inch system is seldom employed now, being replaced by the *Metric System*.

The *dioptre* which is the *metric* unit indicates a lens of such strength as to bring parallel rays of light to a focus at a metre (100 cm.), 39.37 inches, commonly considered 40 inches. A 2 D. lens is just twice as strong and has a focal length of 50 centimetres, or 20 inches. A 10 D. lens would be ten times as strong and would have a focal length of approximately 10 centimeters (4 inches), and so on. The fractions of a dioptre which it is often necessary to use, are expressed decimally. Thus a + .25 D. lens would be one quarter as strong as the 1 D. and would have the focal point 400 cm. or about 160 inches distant.

To change from the inch system to the dioptric, divide the unit 40 by the focal length of the lens in inches. For instance a 20-inch lens would be equivalent to $40 \div 20 = 2$ D. A 13-inch would equal $40 \div 13 = 3$ D. almost.

A concave lens of 1 dioptre (written — 1 D.) is a lens having a negative focal length of 1 metre.

A convex cylinder of 1 D. strength brings parallel rays of light to a focus on a line 1 meter distant, while a concave cylinder of the same strength causes parallel rays of light to diverge as though they came from a line 1 meter behind the lens.

To Find the Optical Centre of Spherical Lenses.—The most convenient way is to draw on a sheet of paper two lines crossing each other at right angles and to view them through the lens (Fig. 26). When the lens is in such a position that the portions of the crossed lines visible through the lens are continuous with the extraneous portions, the optical centre of the lens will be opposite the apparent intersection of the lines. When the cross is opposite any other point of the lens, one or both of the lines will appear displaced toward the thin part of the lens.

Recognition and Measurement of Lenses.—If the crossed lines be viewed through a given lens which is moved from side to side and up and down, if the centre of the cross appears to move in the opposite direction to the motion of the lens in all directions, the lens is a convex one and its strength can be ascertained by placing over it concave glasses of known strength from the trial case till the two neutralize each other, when the cross will appear as through a plane glass—without motion. Thus, if a lens is exactly neutralized by a — 2 D. in all meridians, it must have a strength of exactly + 2 D. If the cross appears to move in the same direction as the lens, it must be a concave one of the same strength as the plus lens which neutralizes it.

If the centre of the cross moves against the lens in one meridian and apparently has no motion in the other, the glass must be a simple convex cylinder, and if the lens be rotated wheel-fashion, till the lines seen through the lens are continuous with the parts outside, the axis of the cylinder will correspond to the direction of the line which undergoes lateral displacement on moving the glass, and the —glass from the trial case which will exactly neutralize this displacement is the measure of the strength of the cylinder. Thus, if through a given lens the cross lines appear stationary when the lens is moved up and down, and to move against when the lens is moved from side to side, we rotate the lens till the vertical line appears continuous with the part outside the lens which will correspond with the axis, and disregarding the other meridian entirely since we know it to be plane, we find the lens of known strength which will stop the lateral motion of the line. If this be stopped by a — 2, the cylinder must have a strength of + 2 in this meridian.

If the cross appears to move against the lens in both meridians, the lens is evidently convex in both. If rotation of the glass causes no torsion of the lines as in Fig. 26, the lens is a convex sphere and is readily neutralized. If torsion of the lines does take place, we must have a cylinder in combination with a sphere, in which case we determine the axis of the cylinder as before and neutralize that and the meridian at right angles separately. If the lateral motion of the vertical line is stopped by a — 3 and the up and down motion of the horizontal line by a — 2, the glass in question must have a strength of + 2 + 1 cyl. axis 90 or vertical.

Concave sphero-cylindrical glasses may be measured in the same way except that the motion of the lines is with the lens and they are neutralized by + lenses.

Occasionally glasses are met with in which the motion is against in one meridian and with in the other. The axes of the glass are to be found and each one neutralized in exactly the same way. Thus, if the vertical axis is neutralized by a — 3 and the horizontal by a + 2, we have a combination of a + 3 cylinder with a — 2 cylinder with axes at right angles to each other.

Since the strength of a lens, the index of refraction being known, depends on the curvature of its surfaces, mechanical means of estimating this curve and the lens power have been devised (Fig. 28). In instruments of this type the two outside pins are immovable and are placed firmly on the lens, while the central one is pressed up in proportion to the convexity, or allowed to project by the concavity, the strength being automatically recorded on the dial as convex or concave. Both sides must be measured and added together to get the total strength of the lens. For instance:—

0 and + 2 would indicate a planoconvex of + 2 D.; + 3 + 3 would indicate a double convex of + 6 D.; — 2 + 5 would indicate a convexconcave of + 3 D.

In combinations of spheres and cylinders one is always on one surface and the other on the reverse. In measuring the cylindrical side of the lens, rotate the lens measure on its central pin as an axis, till the dial indicates the maximum amount when the axis will be at right angles to

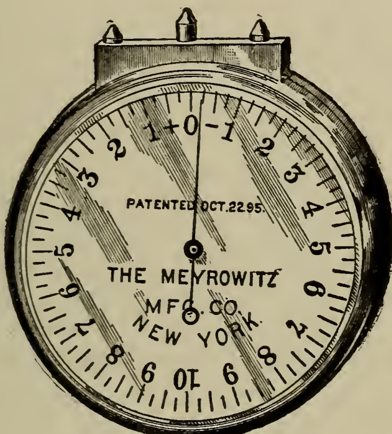


FIG. 28.

the position of the pins, and if tried in the same meridian the dial will register 0.

COMBINATION OF LENSES.—The sign of combination is ⁀.

COMBINING SPHERES.—Any number of spherical lenses placed with their surfaces touching and their optical centres over each other will be equivalent to a single lens of a strength equal to their sum. Thus, + 2 D. ⁀ + 3 D. ⁀ + 1 D. = + 6 D.; or — 5 D. ⁀ — 2 D. = — 7 D.

If a plus lens be placed over a minus of equal strength, the refraction will be nothing, since one will exactly neutralize the other. Thus, + 2 D. ⊃ — 2 D. = 0, but + 4 D. ⊃ — 2 D. = + 2 D., since the minus glass only neutralizes half the stronger plus one.

Combining Cylindrical Lenses.—Any number of cylindrical lenses placed together with their axes in the same meridian will be equal to a cylinder of the strength of their sum. Thus, + 3 cyl ax. 90 ⊃ + 2 cyl. ax. 90 = + 5 cyl. ax. 90, or — 5 cyl. ax. 180 ⊃ — 2 cyl. ax. 180 = — 7 cyl. ax. 180, or — 4 cyl. ax. 180 + 2 cyl. ax. 180 = — 2 cyl. ax. 180.

Two cylinders of the same strength and denomination with axes at right angles to each other are equal to a sphere of the same strength. Thus, + 2 ax. 90 ⊃ + 2 ax. 180 = + 2 sph., since the + 2 ax. 90 will converge all the rays into a vertical line, while the + 2 ax. 180 will converge all the rays in the line to a central point.

Conversely, any sphere may be considered as being made up of two cylinders of equal value with their axes at right angles.

Two cylinders of different strength, but of the same denomination, with axes at right angles, will be equivalent to a sphere and a cylinder. For instance, + 2 ax. 90 ⊃ + 1 ax. 180 = + 1 sph. + 1 ax. 90.

This can be shown by a convenient diagram (Fig. 29).

The + 2 ax. 90 as shown above is equal to 2 lenses of + 1 ax. 90 each. If we combine one of these with the + 1 ax. 180, we shall have a sphere of + 1 D. and have the other + 1 ax. 90 left; hence the combination may be written + 1 + 1 ax. 90. In the same way + 5 ax. 90 + 3 ax. 180 = + 3 sph. ⊃ + 2 ax. 90, since + 5 ax. 90 is the equivalent of + 3 ax. 90 ⊃ + 2 ax. 90 and the + 3 ax. 90 ⊃ + 3 ax. 180 = + 3 sph. and we have + 2 ax. 90 left.

The same sort of diagram may be used to estimate other combinations of cylinders and sphero-cylinders. For example, + 4 ax. 45 + 2 ax. 135.

The + 4 ax. 45 is equivalent to two lenses of + 2 ax. 45, one of which combines with the + 2 ax. 135 to form a + 2 sph. leaving still + 2 ax. 45. Therefore, the combination is equal to + 2 sph. ⊃ + 2 ax. 45.

Example: + 2 sph. — 2 ax. 180? The + 2 sph. is the equivalent of + 2 ax. 90 + 2 ax. 180, the last half of which is neutralized by the — 2 ax. 180, leaving the simplest form of the combination as + 2 ax. 90.

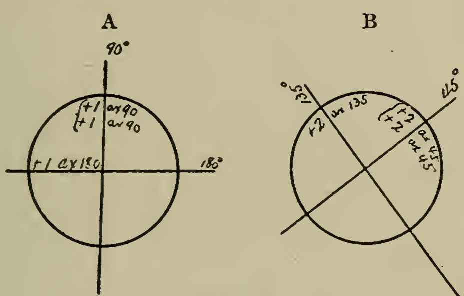


Fig. 29.

Example: + 1 sph. ⊃ — 1 ax. 180? The + 1 sph. is equivalent to + 1 ax. 90 + 1 ax. 180. The + 1 ax. 180 is neutralized by — 1 ax. 180 leaving + 1 ax. 90.

Example: + 3 sph. ⊃ — 2 ax. 180? The + 3 sph. = + 3 ax. 90 ⊃ + 3 ax. 180, the last being partly neutralized by — 2 ax. 180, leaving + 3 ax. 90 ⊃ + 1 ax. 180, which is equal to + 1 sph. + 2 ax. 90.

Crossed Cylinders are glasses having a plus cylinder at one and a minus cylinder at the opposite axis. They are seldom ordered, since it is very much easier both in the fitting and making of lenses to use sphero-cylinders which shall be exactly equivalent.

Example: + 3 ax. 90 ⊃ — 3 ax. 180? To secure the + 3 in the axis 90, we use a + 3 sph. and with a — cylinder at the ax. 180 so strong as not only to neutralize the sphere at that meridian, but to have a — 3 left. Evidently this can be accomplished by combining in this form + 3 sph. ⊃ — 6 ax. 180, or the same thing is accomplished by — 3 sph. ⊃ + 6 ax. 90. These two formulæ are equivalent to each other, but the first is rather preferable as being lighter in weight.

The Toric Lens is a meniscus (Fig. 16F), in which the concave side (a — 6 D.) is placed next the eye, while the anterior surface is made enough stronger or weaker to give the combination the required strength. Thus a — 6 combined with a + 8 would be in effect a + 2 D. Cylindrical corrections can be incorporated with either surface. Toric lenses can be measured by the same methods as flat lenses. Their chief advantage is that in whatever direction the eye is moved it looks nearly perpendicularly through the lens and so avoids a distortion that is unavoidable in flat lenses and which increases with their strength and with the obliquity of the gaze through them. For this reason they are sometimes called *"Periscopic."*

"Punktal" and *"Katral"* lenses are refinements of the same idea.

CHAPTER II.

THE EMMETROPIC OR IDEAL EYE.

No attempt will be made in a book of this character to deal exhaustively with the anatomy of the eye, with which the student is assumed to be already familiar. At the same time it may be well to review briefly the essential factors.

The human eye consists of several tissues or groups of tissue, each of which has a distinct function to perform. Outside is the **Sclera** (Fig. 30), a tough, fibrous envelope which gives form to the eye and by affording a stable attachment to the muscles, makes the motion of the eyeball in various directions possible. The sclera has two openings: a large one anteriorly, into which the cornea is inserted, and a small one posteriorly through which the optic nerve enters the eye.

Lining the sclera is the **Chorioid** (Fig. 30), which is for all essential purposes the nutritional layer of the eye. It is, therefore, composed chiefly of several layers of blood vessels, the larger ones being next the sclera and the smaller ones and capillaries next the retina and vitreous, which it is designed to nourish in part. The chorioid is also pierced by a posterior opening, corresponding to the entrance of the optic nerve, but does not extend quite as far forward as the sclera, terminating in an indentated anterior border called the *ora serrata,* where it is intimately associated with the ciliary body and iris. The chorioid also has an inner layer of dense brown pigment, which performs the function of absorbing light and preventing the internal reflection of rays of light.

Running forward from the ora serrata toward the cornea is the *ciliary body,* triangular in its cross section, and terminating anteriorly just behind the cornea in about seventy ciliary processes, with depressions between them. The part of the ciliary body next the sclera is composed of the longitudinal and circular fibres of the ciliary muscle, while the ciliary processes lying on the muscle are very vascular and are the principal sources of the aqueous humor.

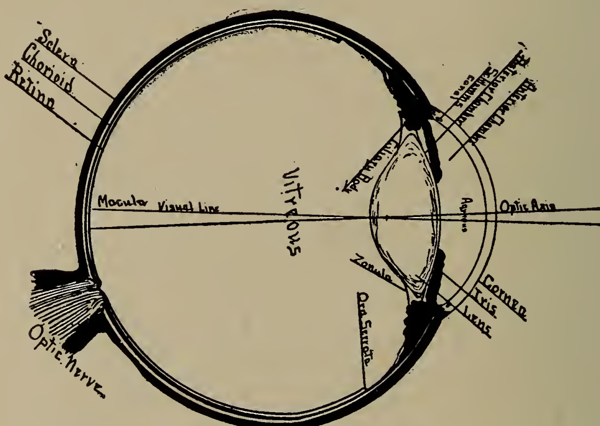


Fig. 30.

Lining the chorioid is the **Retina,** which may be considered as the expansion of the optic nerve and is, therefore, the essential organ of sight. In the living subject it is a thin, transparent membrane of a purplish red color. After death it rapidly becomes opaque, and as its visual purple bleaches out, it appears as a very delicate white membrane. It extends forward in all directions within the chorioid, as far as the ora serrata, and excepting at the head of the optic nerve and the ora serrata, simply lies upon the chorioid without being attached to it. The retina does not really end at the ora serrata, but is continued in a simpler form over the ciliary body and the posterior surface of the iris. There are two points that are particularly noteworthy in the retina: one is the small white disk which lies somewhat to the inner side of the

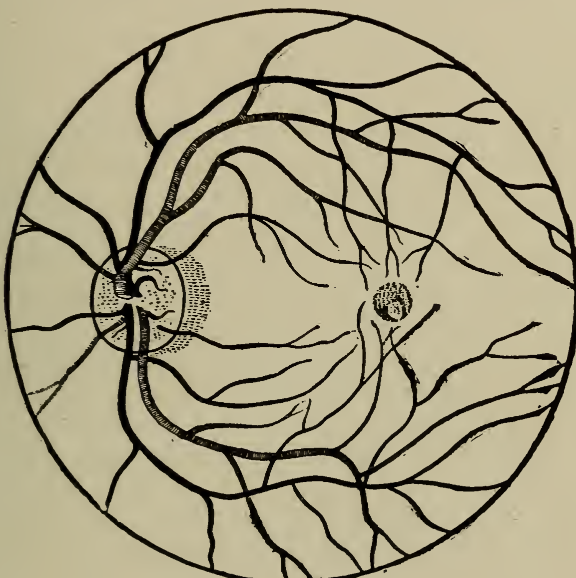


Fig. 31.

posterior pole of the eye and marks the head of the optic nerve from which the retinal vessels emanate, and the second point of interest lies near the posterior pole of the eye. It is distinguished by its faint yellow color, whence the name *macula lutea*. At its centre is a slight depression which is the most sensitive portion of the retina and is called the *fovea centralis*.

The retina will be considered as to some of its points of interest in other chapters. Images of objects are thrown upon it, and it is its function to change the vibrations of the luminiferous ether into nerve stimuli which shall be intelligible to the brain. Just how this takes place, we do not know, but it is certain that under the action of light the visual purple undergoes chemical changes by which it is decolorized. It is very probable that other chemical changes take place which have so far escaped discovery.

If the eye consisted only of the tissues already spoken of, vision would exist, but it would consist only of the perception of light as a glow. Useful vision requires the focussing of light and the formation of images on the retina, which is only possible through the aid of refracting media which we shall now consider.

The **Cornea** (see Fig. 30) is set into the anterior opening in the sclera, of which it may virtually be considered a transparent portion, since the microscope shows that the tissues of one pass over into the other imperceptibly. The cornea is perfectly transparent, except in disease and old age, is slightly elliptical in shape and somewhat thinner in the centre than at the periphery. Its radius of curvature is 7.5 mm. approximately, which is very much less than that of the sclera. Consequently, the cornea projects forward notably. In addition to the scleral tissue present in the cornea, there is an anterior portion representing the continuation of the conjunctiva, and a posterior which belongs to the ciliary body and iris. The cornea acts as a convex collecting lens by the aid of the aqueous.

The **Crystalline Lens** (Fig. 30) lies within the circle formed by the ciliary processes, but in such a way that its border is distant half a millimeter from the apices of those processes. It is suspended by a ligament, or *zonula ciliaris,* which together with the lens divides the eyeball into two cavities: a larger posterior containing the vitreous humor, and a smaller anterior containing aqueous.

The lens is transparent and colorless, and has somewhat the appearance of a biconvex lens, the posterior surface of which is very much more curved than the anterior. The lens is enclosed in a transparent capsule and is composed of concentric layers of varying density, those at the centre having a regularly increasing density and refracting power. The optical function of the lens consists in bringing the rays of light that are already convergent from passing through the cornea still further together, till they focus on the retina.

The **Aqueous** (Fig. 30) is a transparent, thin fluid, probably secreted by the iris and ciliary body which lies between the cornea and the lens. It has practically the same density as water, and its function is one of nutrition as well as refraction. A moment's consideration will show that the cornea has one convex surface and one concave, which would practically neutralize each other as do the sides of a watch crystal; but the presence of the aqueous serves to nullify the action of the posterior surface to a large degree, and the cornea and aqueous act together as a powerful convex lens.

The **Vitreous Humor** (Fig. 30) fills the posterior part of the eye. It is a transparent, jelly-like substance, inclosed in the meshes of an equally transparent reticulum. The vitreous is surrounded by a structureless, transparent membrane, called the *hyaloid* membrane; it presents a fossa for contact with the posterior surface of the lens and is in contact with the retina. It has a still further convergent action on rays of light.

The **Iris.**—The cornea and lens, with the vitreous and aqueous acting together, have an action on rays of light like that of a very powerful convex lens, and we have seen that in powerful lenses the peripheral rays of light are refracted so that they come to a focus sooner than the central rays, constituting the so-called spherical aberration which is a source of confusion, and that if these peripheral rays be excluded, the image is much more distinct. As in the camera or microscope, the image formed through a pin-hole aperture is just as distinct if the light is bright enough, and it is the function of the iris to regulate the amount of illumination and cut off the peripheral rays.

The iris is a disk-shaped membrane with a central opening, the pupil. It springs peripherally from the anterior portions of the ciliary body, from which point it stretches over the lens, its pupillary border resting on the anterior capsule upon which it slides during the movements of the pupil. The iris consists essentially of numerous blood vessels running in a radial direction from the periphery to the pupillary border, which are enclosed in a thick adventitia and surrounded by loosely arranged cells which fill up the space between them.

On the posterior surface of the iris is a continuation of the retinal pigment layer which makes the iris absolutely impervious to light except that admitted through the pupil. The posterior surface also contains numerous elastic fibres which run radially from the ciliary border to the pupil, and by the contraction of which the pupils dilates. The natural position of rest of the iris, then, is with the pupil semi-dilated. At the pupillary margin is the thin flat band of muscular tissue which causes the pupil to contract, called the *sphincter iridis*.

The **Refracting Media** of the eye have their characteristic density and refraction index as given in the table below from Foster:—

Water	1.3333
Aqueous	1.3366
Vitreous	1.3394
Lens Periphery	1.39
Lens Nucleus	1.43
Cornea	1.3333

Rays of light, in reaching the retina, traverse in succession the following surfaces and media: the anterior surface of the cornea; its substance; its posterior surface; the aqueous humor; the anterior surface of the lens; its substance; the posterior surface of the lens; and the vitreous humor; so that we have, including the air, four surfaces and four media.

The air as one of the media is not to be overlooked, for the difference in density between it and the cornea is a powerful element in the refraction of rays, and if we substitute water for it by placing the eye beneath the surface, its refracting power is much reduced.

This constitutes a rather complicated system which, for purposes of study, may be simplified somewhat. For instance, the cornea is not absolutely homogeneous in its structure and its anterior surface is not absolutely parallel with the posterior one; but if we consider them as parallel and the substance nearly homogeneous and having the same refracting power as the aqueous, it is evident that the cornea may, without serious error, be considered as consisting of one surface, the anterior, separating two widely differing media—the external air and the aqueous.

In the same way, without fear of serious error, we may disregard the varying refraction of the concentric layers of the lens and consider it as a homogeneous substance bounded by an anterior and a posterior surface.

We have, therefore, to deal with three surfaces and three media:

First, the anterior surface of the cornea, where rays of light passing from the thin air into the denser and practically homogeneous medium afforded by the corneal substance and the aqueous, are very powerfully refracted.

Second, the convex anterior surface of the lens, where the rays pass from the aqueous into the more refractive lens.

Third, the posterior surface of the lens where the rays pass into the less refractive vitreous.

The surface of the cornea and the two surfaces of the lens are all approximately centred on a line which passes perpendicularly through the centre of the cornea, the centre of the lens and the centre of the fundus or back part of the eye.

This imaginary line is called the *optic axis* (Fig. 32). Some authorities insist that it passes through the fovea posteriorly, while others argue that it passes a little above and to the nasal side, but we shall find later that the position of the fovea varies somewhat in different eyes. It has, however, been shown mathematically that a complex optical system of no matter how many surfaces and media, if centred on one axis, may be treated as though it consisted of their equivalent in a single surface.

Such an eye in which the refracting media are replaced by one refracting surface of such a strength that parallel rays are brought to a focus on the retina is called the "Reduced Eye" (Fig. 32). Its refracting surface must necessarily have a sharper curve or a higher index of refraction than the human cornea.

The *cardinal points* of such an eye are as follows: the *principal point P,* where the imaginary surface cuts the optic axis, the *nodal point N,* the *posterior principal focus,* which would fall on the retina and the *anterior principal focus,* where parallel rays emerging from the eye would cut the optic axis.

By aid of this simplified or reduced eye we are enabled to trace out the paths of light and study the formation of images on the retina.

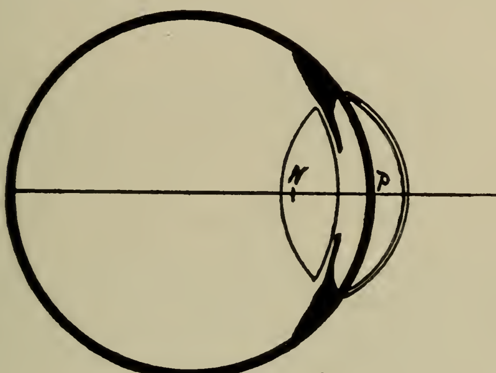


FIG. 32.

Let Fig. 33 represent an eye in which, while the cornea and lens are shown, all refraction takes place at the surface, indicated by the line passing through the optic axis at *P,* representing an imaginary medium which shall be the equivalent of those actually present. Then *P* will be the anterior principal point and N the nodal point. The formation of the retinal image is exactly like that thrown on a screen by any convex lens. Rays of light from the point *A* pass through the nodal point unrefracted to *A'*, where they are joined by the other rays from *A* which have passed through other portions and have been refracted. *A* and *A'* are therefore conjugate foci, as are *B* and *B'*. The points between *A* and *B* have their corresponding conjugates between *A'* and *B'*, and therefore *A'B'* constitutes the image of *AB* formed on the retina which is evidently a real image and inverted. Hence, supposing the eye to be in an optical condition, in which a distinct image of the arrow is formed on the retina, we can find the position of the tip of the

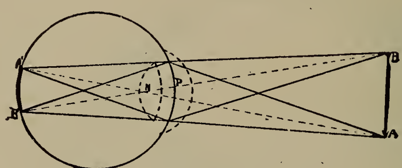


FIG. 33.

arrow on the retina by drawing a straight line from the tip of the object through the nodal point, while the image of the notch of the arrow and of the intermediate points is found in the same way by drawing straight lines through the nodal point.

Visual Angle.—The visual angle is the angle formed by lines drawn from the extremities of the object of regard through the nodal point of the eye, or the angle which the object subtends at the nodal point of the eye (Fig. 34).

Evidently, if the object is nearer the eye, the visual angle is greater, and if further away, it is smaller.

The size of retinal images corresponds to the visual angles at which they are seen. Therefore, objects having the same visual angle will have equal retinal images and appear the same size.

This is modified somewhat as the result of experience. For instance, a row of telegraph poles appears to diminish in size as their distance increases, because their visual angle becomes less, but we know them by experience to be of similar size, which leads our judgment to rectify the erroneous impression of our vision.

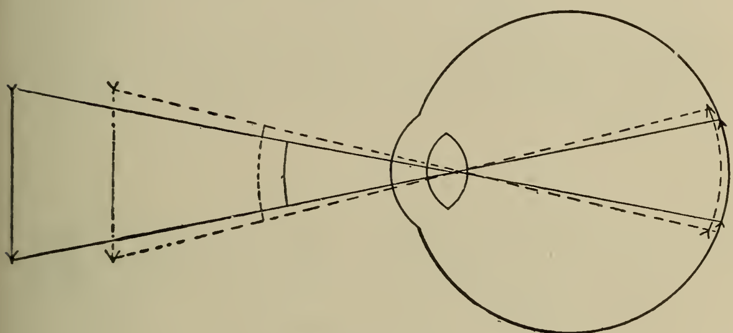


Fig. 34.

Minimum Visual Angle.—This is the smallest angle at which objects can be seen and identified, and is also spoken of as the *limiting angle* of vision. This varies considerably in different individuals. Those who are young and with strong nerve perception, can see objects under a smaller visual angle, or in other words, when the object is at a greater distance. Naturally, too, the visual angle will vary somewhat in the same individual under different conditions of illumination, atmosphere and retinal fatigue. It is necessary to have some fixed standard by which we can measure the visual acuity of patients, so as to know whether it is above or below the normal, and to be able to inform ourselves later whether it has increased or grown less. Such a standard is afforded by the average visual acuity of the emmetropic eye. It has been found experimentally that all objects which subtend a visual angle of five minutes are distinctly visible to the normal eye, while if the angle is less than this, they become indistinct. Based on this, we have a series of test letters and objects of such size that at stated distances they subtend angles of five minutes vertically and horizontally. The ordinary test card is a good example. It contains at the top a letter or figure so large that at a distance of two hundred feet, or 61 metres, it subtends an angle of five minutes. A second,

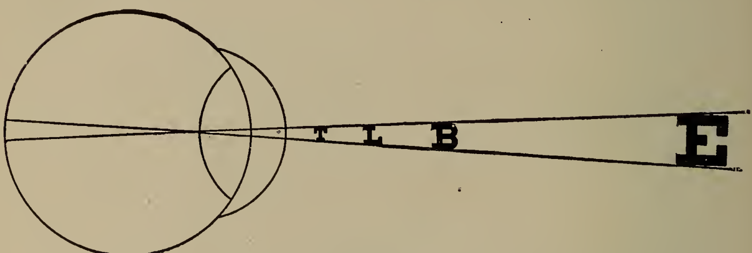


FIG. 35.

somewhat smaller, series subtends the same angle at one hundred feet (thirty metres); another at seventy feet (twenty-one metres), and so on down to a series of very small letters at ten feet (three metres). Evidently, these all subtend the same angle and, consequently, the eye which can distinguish the small letters at ten feet, can distinguish equally well the larger ones at two hundred, and *vice versa.*

Accommodation.—We have seen that rays of light coming from a source so distant that they are practically parallel, are so bent by the ideal or emmetropic eye as to come to a focus exactly on the retina and forming a distinct image, make distant vision possible. Evidently, if the rays come from a source close at hand, they will be divergent and will be caught by the retina before they come to a focus.

Let us consider for a moment with a simple convex lens and a screen the effect of such rays when intercepted away from their focus. (Fig. 36). Rays of light from a point after passing through such a lens, are collected in the shape of a cone of light, and if the screen be placed exactly where the rays cross at the apex of the cone, a point is formed on the screen which is the exact image of the original source of light. If the screen is moved toward

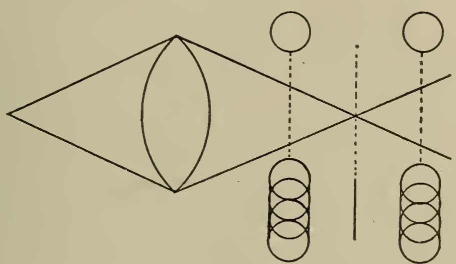


FIG. 36.

the lens, the appearance on it is that of a circle of light formed at the place where the screen truncates the cone, and the circle becomes larger and less distinct the further from the focal point it is formed. The same thing takes place, if the screen be moved in the opposite direction beyond the focal point, where the rays after crossing have become divergent. Exactly the same thing takes place in the human eye, when rays enter which would come to a focus behind the retina, and a circle formed on the retina instead of a point.

If the rays come from two distinct, separate points, the image formed consists of two circles which may overlap each other and give the impression of an indistinct oval. In the same way a line may be considered as composed of a number of points, each of which under these circumstances appears as a circle, the final result being of a broad band with oval ends and indistinct outline. Every visible object is made up of imaginary points, which must have their conjugates focus exactly on the retina to form a distinct image of the whole object, and if part or all of these points give the impression of circles, distinct vision is impossible. These circles are called *diffusion circles* and are formed on the retina in every one of the various anomalies of refraction, and it is to prevent their formation or to relieve the eye of the task of preventing them, that we prescribe glasses.

In the photographic camera these diffusion circles may be obviated in three ways: by changing the distances between the lens and the ground glass by moving one or both; by moving the object further away from the camera; or by increasing the strength of the lens. In the living eye some of the lower animals can increase their refractive power by pushing the lens backward and forward at will; but man has choice only between the last two alternatives and increases his refraction by increasing automatically the strength of his refracting media, and when this fails in old age, resorts to pushing the object away from his eyes. This change in refraction takes place chiefly in the crystalline lens through a physiological process of accommodation, to understand which it may be best to review briefly the anatomy of the tissues.

In the first place, the lens is composed of tissue which is elastic and tends to assume a spherical shape, when unrestrained. When the eye is at rest, however, many experiments show that the lens is very much flattened, especially its anterior surface, and this is supposed to be due to the tension of the fibres of the zonula which spring from the ciliary processes and chorioid, pass forward on the inner surface of the ciliary body and split into two layers, one of which becomes continuous with the anterior capsule of the lens and the other with the posterior one. When these fibres are tense, the lens becomes oval in its cross section, and when they are relaxed, the cross section is a circle. This relaxation is effected by the ciliary body

Fig. 37.

or muscle, which is an annular tissue attached all the way round just behind the junction of the cornea and sclera and with longitudinal fibres running back to inosculate with the chorioid at the ora serrata.

When the ciliary muscle contracts, the longitudinal fibres pull the chorioidal tissue toward the fixed point of the muscle at the corneal margin, and in doing so, also pull forward and relax the fibres of the zonula which are interwoven with the muscular tissues. The main factor, however, is probably the annular portion of the muscle which has a sphincter-like action, and in contracting the size of the ring produces a complete relaxation of the zonula. It is for this reason that individuals who have to use the accommodation unduly have a hypertrophy of the ciliary muscle and especially its circular fibres.

As the surface of the lens assumes a more curved shape, there is necessarily produced a corresponding diminution in its equatorial diameter, the equator constantly receding toward the axis of the eye and keeping a fixed distance from its ciliary muscle as it contracts.

The increase in curvature affects both surfaces, but especially the anterior, which advances, while the posterior does not materially change its position in the fossa patelliformis. By this central forward-bulging of the lens the iris is pushed forward in the centre, while it recedes slightly on the periphery, and at the same time there is a contraction of the pupil.

In order to measure the increase in power of the lens in the act of accommodation, we must determine two points. One of these is the so-called *far point*, for which the eye is focused when completely relaxed, which in the emmetropic eye is infinity; and the other the *near point*, or the nearest point at which distinct vision is possible by exerting the entire accommodation.

The far point is determined by testing at a distance of twenty feet with the trial card, in which case the emmetropic eye would have a vision of 20/20. The near point is determined by bringing fine type closer and closer to the eye, till distinct vision ceases. The distance between the near and far points is the *region* of accommodation, while the *amplitude*, or range, or power, of accommodation is the difference between the refraction of the eye at the far and near points in dioptres.

For instance, in the emmetropic eye which is adapted to parallel rays, if the object of regard be moved up to a distance of one meter, it can be seen by the interposition of a lens of 1 D., or by accommodating an equivalent amount. The object at ten inches or a quarter of a metre could be seen by aid of a 4 D. glass or by accommodating, and if the object cannot be brought nearer to the eye without blurring, it is evident that the near point is at ten inches while the amplitude or amount of accommodation is 4 D. If the near point of the eye were at five or four or two inches, the amplitude would be 8 D. or 10 D. or 20 D., respectively.

The power of accommodation is temporarily abrogated by the use of atropin, and also varies greatly with the age of the individual. It is greatest in extreme youth and diminishes regularly with age, until it disappears in old age altogether. This loss of power is the result of a physiological diminution of the elasticity of the lens substance which comes with age. No matter how powerful the action of the ciliary muscle, it can only permit the lens to assume the shape caused by its internal elasticity, and as it becomes hardened and inelastic, it fails to respond and remains constantly flat, causing the near point to recede. The state of the accommodation at different ages is well shown in the following diagram from Donders, which, however, shows only average measurements from which there are many and wide variations (Fig. 38), as shown by Duane.

Thus, at ten years the emmetrope has a near point of 7.1 cm. equal to 2¾ inches, and the accommodation is equal to a lens of 14 D. At 20 his near point has receded to 10 cm. or four inches and his power is 10 D., while at 45 his near point is nine inches and his power has fallen to 4.50 D. After that he has difficulty in reading fine type without holding it further and further from his eyes and soon has to bring his near point up by wearing reading glasses.

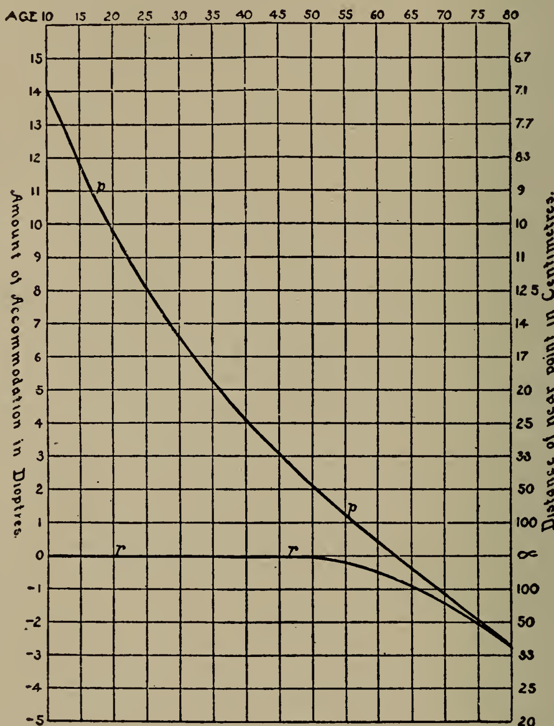


FIG. 38.

THE EXAMINATION of even a normal eye includes the testing of a number of different functions, and it is advisable for the student to get the habit of making the examination in a regular and orderly manner, making a careful permanent record of the facts as ascertained. This record will be very much more valuable, if it contains a history of the patient, not only the eye history and present eye symptoms, but the family and personal medical history, making special note of diseases which may affect the integrity of the eyes, and also of many functional troubles which at times result from ocular imperfections. A very convenient way of keeping such records is by means of a card index, or better still, a loose leaf system, the history being recorded on one side at such length as seems desirable, while on the other side is the examination record. The *family history* should include illness and eye diseases which might be hereditary, especial note being made of conditions like migraine, epilepsy, neurasthenia, which might be either dependent on eye conditions or indicate a hereditary nervous instability and so make otherwise unimportant ocular defects an overburden.

The *personal history* should include data of age, occupation, whether taxing to the eyes or not, of habits which may affect the eyes such as the use of alcohol, tobacco and drugs, of all severe illnesses which might have left diseased eye conditions, and especially of recent ill health which might cause a temporary ocular insufficiency. The nervous diseases, such as neurasthenia, hysteria, epilepsy, locomotor ataxia, neuralgia, should be recorded, and especial attention paid to headache, its frequency and severity, whether it is hereditary like migraine with nausea and scintillating scotomata, whether it occurs daily or only occasionally, whether it appears to be caused by use of the eyes and relieved by their disuse, whether near or distant vision is the most trying and whether it is a frontal or an occipital. Inquiry should be made as to digestion, circulation, etc., particularly as regards functional disorders.

The data regarding the eyes themselves should include all the symptoms of which the patient is aware, such as pain, photophobia, failure of vision, whether for near or far, the existence of scotomata, diplopia, and also a record of the objective peculiarities, such as inflammation, malformation of the lids, inequality of the pupils, strabismus, etc.

The physician then proceeds to record the following facts:—

1. The distant vision in each eye, with and without glasses, indicating whether a cycloplegic was used or not.

2. Ophthalmoscopic examination, including reaction of the pupils, both singly and consensually, the transparency of the various media, the conditions of the fundus and an estimate of the refraction. The use of suitable rubber stamps will facilitate these records.

3. Retinoscopic examination of refraction.

4. Ophthalmometric measurement of corneal curve and radius of curvature.

5. Near vision: measurement both of visual acuity and amplitude of accommodation, whether normal and sufficient for needs or not.

6. Motility of the eyes. Relative position of the optic axes in state of rest. Involuntary or fusion power. Voluntary or rotatory capacity.

7. The field of vision. Peripheral retinal sensitiveness.

8. Color sensation.

We have seen that the average eye can perceive clearly objects which subtend a visual angle of at least five minutes and our test cards for estimating the visual acuity are based on this fact. They generally contain, as shown in the illustrations, a series of letters of different sizes, which subtend this angle at different distances varying from two hundred feet or sixty-one metres for the largest down to eight feet or 2.5 metres for the smallest. These test types are generally black on a white background, but sometimes the background is cream-colored, which is softer to the eye. Cards are made also in which the letters only are white,

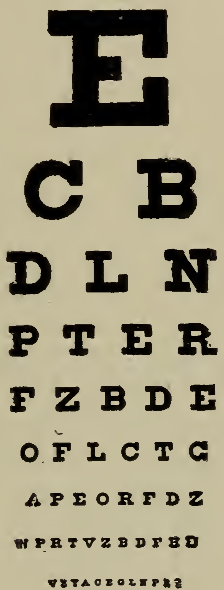


FIG. 39.

while the background is black. For normal eyes the visual acuity is usually slightly greater when tested on the first variety, but eyes which are tired and strained or inflamed, with some photophobia, will frequently appear to much better advantage with cards which do not reflect so much light.

There are many test objects more scientific and accurate than letters and numbers, some of which can be distinguished at considerably greater distances than others of the same size, but in the consultation room the letters have proven far more convenient and time saving than any so far suggested.

For children cards have been devised with kindergarten objects of a size corresponding to the ordinary charts, while for illiterates numerals or the letter **E** with the prongs pointing in different directions are made, the patient being expected to indicate by gestures the direction in which they point.

The selection of test cards is a matter of individual choice, but the office should be provided with several to avoid the memorizing into which patients, especially children, unwittingly fall.

Tests of distant vision should preferably be made at a distance of twenty feet or more, but when this cannot be readily obtained, the space can be doubled by having the patient read the letters from a mirror across the room as they are reflected from a card beside him, when the apparent distance is equal to the sum of both incident and reflected rays. Owing to the lateral inversion, a special card with letters reversed laterally is provided. These tests can be made by a good day light, but it is generally much better to have the test cards artificially illuminated, as much greater uniformity is secured in this way. Each eye should be tested separately, the other being screened, but not closed, and as the patient always sees better with one eye when he is also using the other, it is often better to use, instead of a screen or disc, a strong convex lens. The patient is then using both eyes, but all that he sees distinctly is seen with the eye which is being tested.

Each letter on the cards has marked over it in both feet and metres the distance at which it should be read, and the record of acuity will consist of a fraction, the numerator of which is the distance at which the patient sat from the card, and the denominator the size of the smallest row of letters correctly read. These fractions being records of actual conditions are better left unreduced. If the patient reads only part of a line, the number of letters missed should be indicated by asterisk or question mark for each. If at the usual distance the patient can see no letters on the card, he must be allowed to approach till he can read, and the distance now becomes the numerator of the fraction on record. Patients, who are incapable of perceiving letters, may be tested as to their ability to count fingers at a maximum distance, which is carefully noted. Eyes not even capable of distinguishing form in fingers, may be tested by their ability to perceive light from a candle or a mirror.

It is advisable for the student to get into a regular and unvarying method of procedure both in the examinations and recording of the results, as he is thus very much less likely to overlook facts or make mistakes. The abbreviations R. E. or O. D. (oculus dexter) are used for right eye, and L. E. or O. S. (oculus sinister) for left eye.

Vision O. D. 20/20; O. S. 20/200 means that the patient was seated at a distance of twenty feet from the card and with the right eye he saw the letters which he should see at that distance, while with the other eye for some reason he could only see the letters which should have been visible at 200 feet. The same record expressed in metres would have been :—

R. E. 6/6 or VI/VI;

L. E. 6/60 or VI/LX.

The visual acuity with appropriate glasses is also part of the record, as follows :—

For instance, a patient who accepted a certain glass with or without improvement, would have his vision recorded thus:—

R. E. 20/70 ? ? + 2 ⌒ + 1 ax. 90 = 20/30

L. E. 20/200 — 2 ax. 1.80 = 20/30.

To determine the near point, we employ small cards on which are printed letters of various sizes, ranging from very small up to moderately large letters. The first cards for this purpose, devised by Jaeger, were entirely empirical being printed from type of various sizes found in every printing office. Later on, Snellen introduced test type on the same principle as his large wall types, each letter subtending a visual angle of five minutes at a given distance. Above each series of letters is printed the distance at which it should be normally visible, from twenty-five centimetres (ten inches) up to two hundred centimetres.

The patient should be seated with a good light falling on the card from a source over his shoulder. With each eye separately he then picks out the finest type which he can see distinctly and approaches the card toward the eye till the letters begin to appear hazy. The distance between this point and the eye is carefully measured in the metric or the inch system, and the record entered as follows:—

Near V. = 0.5 D. at 25 cm.,

or less scientifically, but approximately:—

No. 1 Jaeger at ten inches.

Very often, as we shall see in the chapter on "Presbyopia," the patient cannot read fine print without glasses, when we record the glass selected, the size of type it enabled the eye to perceive and the nearest and farthest point at which vision was distinct. For instance,

with 2.50 sph. No. 1 Jaeger 10-15 inches

or Snellens .50 D. 25-37 cm.

When patients are illiterate the same purpose is subserved by the hair optometer (Fig. 40), which consists of a small frame across which are stretched several hairs or fine threads. The patient approaches the instrument to the eyes till the strands cease to be distinct, when the distance is carefully measured by a tape attached to a hook on the handle.

The use of the trial case will be taken up more fully in chapters dealing with various forms of ametropia, but a description of the contents of the trial case and its purpose may not be amiss. Each case contains a series of convex

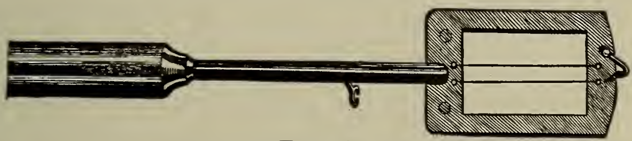


FIG. 40.

and of concave spheres running from .25 D. up to 20 D. by varying graduations, and of convex and concave cylinders from .25 D. to 5 D. As a rule, the more minute the subdivisions of the dioptres from .25 to 3, the more useful the case. In the convex glasses, for instance, whether spherical or cylindrical, one is constantly making use of fractions of the first dioptre, while the stronger lenses are less frequently called for, and the strongest only occasionally.

To a less extent the same thing is true of the concave lenses. Each case also contains a set of prisms, varying in strength from ½ △ to 20 △, as well as a series of colored and smoked plain glasses and perforated disks, whose use will be more fully explained later on. Especially important is the trial frame, which should be light, but not flimsy, capable of adjustment to suit various types of features and of being firmly held in this position.

CHAPTER III.

OBJECTIVE EXAMINATION OF THE EYE—OPHTHALMOSCOPY.

We have seen that the emmetropic eye is one in which parallel rays of light come to a focus on the retina when the ciliary muscle is completely relaxed, that it is capable of seeing distinctly all objects, whatever their distance, which subtend a visual angle of five minutes, and that it has a definite average power of accommodation depending on the age of the individual.

The absolutely emmetropic eye is one of the rarest things in nature. It is to be distinguished from the far-sighted or *hyperopic* eye by which parallel rays are not refracted strongly enough and consequently come to a focus behind the retina; the nearsighted or *myopic* eye by which parallel rays are too strongly refracted and come to a focus in front of the retina; and the *astigmatic* eye in which the refraction in different meridians varies so that either one or both fail to focus on the retina because of over- or under-refraction. In one individual the vision may be very much below normal, while another may preserve the keenness of his vision by the use of his accommodation, in which case he is likely to suffer from his over-exertion.

In either case it is the object of the refractionist to discover the direction of the rays which do focus on the retina, and the lens, or combination of lenses, by aid of which he shall be able to focus parallel rays on his retina. In other words, we try to make the individual emmetropic by aid of glasses and so either improve his vision or relieve the strain on his ciliary muscle, or both, and in case his vision is not improved, to discover the cause: whether the disturbance be due to changes in the refracting media or to lessened perception on the part of the deeper structures.

In making this examination, too much stress cannot be laid on the value of system in our method, lest we carelessly overlook some important fact. After examining the condition of the lids and conjunctiva, we begin the inspection of the refracting media by the method of:

Oblique illumination consists in the concentration of light on the cornea by a very strong convex lens.

From May "On the Eye." Courtesy of Wm. Wood & Co.

Fig. 41.

A light is placed to one side and somewhat in front of the patient, and its rays are concentrated by a 13 to 15 D. lens into a cone of light whose apex is thrown on the cornea. This is sometimes called "focal illumination," since the point at the focus of the lens appears with great sharpness, especially if the examination be conducted in a darkened room. By this method we can recognize even very small opacities of the cornea which intercept the light and at once become visible. It is also well at times to test the sensitiveness of the cornea to the touch, with a bit of cotton, for the anesthesia which is suggestive of hysteria or glaucoma. Throwing the cone of light on the deeper portions of the eye, we note the anterior chamber, particularly its depth, and then pass to the iris, observing whether its radiations are distinct and its color like its fellow. Throwing the cone of light off and again on the pupil, we notice whether the iris reacts to light and whether sharply or sluggishly, also when it dilates, whether the pupil is free, round and central, or whether it is irregular from adhesions. We also

Fig. 42.

note any tendency of the iris to shake like the edge of a drapery, as abnormal and suggestive of a dislocated lens, and then investigate to see whether illumination of one eye causes a consensual contraction of the pupil in the other. Furthermore we test the reaction of the pupil to accommodation and convergence, and, lastly, note whether the pupil is a clear black or not. Even with the dilated pupil we can see very little of the lens by lateral illumination, unless there are opacities present. When it is perfectly transparent, we can demonstrate its presence by the presence of the Purkinje-Sanson reflexes.

If in a dark room a candle be placed before and somewhat to one side of the eye, a reflection may be seen from the three refracting surfaces of the eye. The one on the cornea is large and easily seen, being an upright image of the candle flame which, when the candle is moved, moves in the same direction. The one formed on the anterior surface of the lens is upright and larger than the preceding one, but so very faint as to be seen with great difficulty. The one formed on the posterior concave surface of the lens is the one on which we rely. It is very bright, but very small and inverted, and seems to move in the opposite direction to any movement of the candle. If it is absent, either the lens is wanting or so lacking in transparency that it can readily be recognized by other methods.

In examining the interior of the eye, it is advantageous, though not necessary, to have the pupil widely dilated.

The Ophthalmoscope.—The ancients very early observed that the eyes of many animals glowed in the dark "like coals of fire," and it was long known that the human eye, when placed under water, emitted light in the same way; hence it was supposed that the eye was the source of light till it was demonstrated that death makes no change in the phenomenon. Later it was shown that almost any eye in which the pupil is dilated becomes luminous under proper conditions and that the eye is not the source of light, but merely reflects the light it receives, the red color being due to the blood-vessels in the chorioid. The eyes of most wild animals are highly hyperopic, or weak in their refractive power, and hence emit rays of light which are widely divergent, and to the observer who can put himself in the path of any of these rays, the pupils appear luminous. When the normal human eye is placed beneath the water, the refraction of the cornea and aqueous are practically nullified, and rays of light from a candle after entering the eye, come out widely divergent, making the pupil appear luminous; but if the water be removed without changing the position of the light or the eye, the latter ceases to be luminous, because the rays now come out parallel, and if the observer places himself in their path, his head cuts off the source of light. In the albino, whose eye is lacking in pigment, light can enter the eye through the sclera and chorioid, and consequently it appears luminous, whatever the position of the observer. Evidently, to view the fundus of the normal eye, the eye of the observer must be in a direct line with the light without cutting it off or being dazzled by it. This problem was partly solved by an ancient observer who looked through a hollow tube held in the flame of a candle. Helmholtz, only sixty years ago, established the theory of the ophthalmoscope and made the first practical instrument which has passed through many stages up to the perfected instruments of to-day. Essentially the ophthalmoscope, of whatever pattern, consists of a mirror which reflects light directly into the patient's eye, while the observer places himself in the path of those rays by gazing through a small hole in the centre of the mirror.

This is sufficient for observing the fundus of the emmetropic eye, but when the eyes of either observer or observed are ametropic, a series of lenses placed behind the mirror gives us all the essentials of the refracting ophthalmoscope of to-day. Perhaps the most popular ophthalmoscope, in America at least, is the Loring or one of its modifications, which is shown in the illustration. In it the mirror is slightly concave so as to concentrate the light, and the lateral edges are cut away so that the mirror may be tilted to either side, which is a great help in directing the rays from a lamp beside the patient's head into his eyes. Behind the sight-hole in the mirror is arranged a revolving disc containing an aperture and lenses ranging from + 7 D. to — 8 D., which can be brought in turn behind the hole in the mirror. In case of need there is over the disc a movable quadrant containing a + .50 and a + 16 D. and a — .50 and a — 16 D., any one of which can be used in conjunction with any lens in the disc. It is thus possible to proceed by half dioptres all the way from + 23 to — 24 D.

The other ophthalmoscopes in use differ from the Loring type chiefly in their method of changing the

FIG. 43.

strength of the lenses behind the mirror. Any one of them made by responsible parties will be satisfactory.

The source of light is a matter of choice. It may be oil or gas, or electric light. If the electric bulbs are used, they must be of frosted or ground glass. These may be laid on the patient's pillow in bedside work. Several ophthalmoscopes are available in which the light comes from a tiny electric lamp, activated from a dry cell in the handle. They are very easy to use and are especially adapted to bedside work in the hospital, where ordinary means of illumination are not convenient without making the patient sit up. When the patient can sit up in bed, a thorough examination can be made by aid of a candle.

The ophthalmoscopic examination should be made in a dark room, the patient being seated on a comfortable chair, and the lamp should be about on a level with the patient's eye and on a plane considerably back of it, so that light from it may be thrown into the eye without unnecessary maneuvers. The observer should be seated beside the patient and facing him in such a way that their eyes are about on a level and near enough to approach his eye very close to his patient's. Almost necessarily the surgeon must use his right eye in examining the right eye, and his left in examining the left, since otherwise his nose will come in contact with the patient's and he will not get close enough to examine satisfactorily.

Fig. 43*a*.

The Direct Method.—Placing the ophthalmoscope before his eye and looking through a + 6 or + 7 lens, the physician should first throw the light into the eye from a distance of twelve or fifteen inches and gradually approach his head to that of the patient. In this way he not only has the advantage of the condensation of light from the concave mirror, but when he approaches to the proper distance, sees all the details magnified by a convex lens. Turning the mirror to one side so as to throw the pupil in the shadow and then exposing it to the bright light suddenly, he should note whether it reacts properly to the light stimulus. The light reflected from the retina returns to the observer's eye, so that the whole pupil seems illuminated by a brilliant glow which, if perfectly clear, indicates that the refractive media are transparent. He should note whether the pupil is round, or whether its edge is adherent at any point to the lens, causing it to expand and contract unevenly, or whether any spots of pigment on

FIG. 44.

the lens near the margin indicate previous adhesions. If there are spots of this kind or opacities in the cornea, lens or vitreous, they will interfere with the return of light to the eye of the observer and will appear as black spots or masses against the red background. Then, while watching these closely, the patient is directed to move his gaze up or down, and the surgeon notes carefully their position relative to the margin of the pupil and can tell quite accurately on which of the refractive media they are situated.

Suppose, for instance, an opacity that when the patient looks straight ahead appears like a black point in the centre of the pupil. When the eye turns upward, it moves wheel-fashion round a centre of rotation, and objects in front of the pupillary plane will seem to move upward while those behind will have a corresponding motion downward. If the opacity is in the cornea, it will appear to

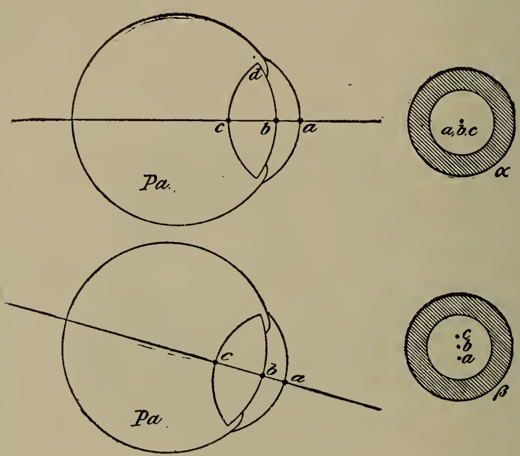


FIG. 45.

move in the direction in which the eye is turning toward the margin of the pupil and will finally pass out of the illuminated pupil in front of the iris. If it is in the anterior chamber, it will move in the same direction, but being nearer the pupil, will not move so fast nor so far.

If on the anterior surface of the lens, which is practically in the same plane as the iris, the opacities will maintain the same relative position in the pupil, whichever way the eye may move. If they are in the substance of the lens or on its posterior surface, which are in planes behind the iris, they are, as it were, behind the hub of the wheel, and, when viewed from the front, seem to move in the opposite direction to the motion of the eye. If the opacities are in the vitreous, they move down when the eye moves up, and *vice versa*, and their motion is apparently more rapid, as they are further from the iris and nearer to the posterior pole of the eye. The result is the same when the patient keeps his eye quiet and the observer moves from one position to the other.

Opacities can also be localized by their relation to the corneal reflex. An imaginary line drawn from the sight hole of the ophthalmoscope through the light reflex seen on the cornea, must be perpendicular to its surface and so pass through its centre of curvature, which we know to be in the back part of the lens. An opacity which always appears very close to the light reflex when viewed from several directions must be near this centre of curvature. If it invariably seems nearer the centre of the cornea than the reflex it must be proportionately further forward, while if it seems invariably outside the reflex it must be further back.

It is not intended in a work of this kind to consider the various causes of opacity in the refracting media, but having ascertained that there are no opacities to obstruct a view of the fundus, the student should—looking now through the aperture—approach his eye to that of the patient, being careful meanwhile not to lose sight of the reflex. When the light from the ophthalmoscopic mirror is thrown on a screen or on the patient's forehead or cheek, it forms an oblong of condensed light, in the centre of which will be seen a dark spot which corresponds to the aperture in the mirror. If the ophthalmoscope be moved in such a way that the dark spot coincides with the pupil of the patient and approaches as closely as possible, a good view of the fundus will be obtained if both eyes be emmetropic and with accommodation relaxed. The beam of light thrown into the patient's eye is reflected from the retina, and if the eye be emmetropic and completely relaxed, emerges in parallel rays. A central bundle of these rays passes through the aperture in the mirror and entering the eye of the observer should come to a focus exactly on his retina, giving a clear picture of the fundus. But here a difficulty confronts the beginner, for conscious that he is looking at an object very close to his own eye, he insensibly accommodates and the rays focus before reaching his retina, and he sees indistinctly. The ability to relax his own accommodation is the basis of all successful work with the ophthalmoscope, and if the student will exercise patience and try to imagine that he is looking at an object far from him, at the same time learning to keep both eyes open, he will gradually learn to relax his ciliary muscle. He should use every opportunity to examine eyes with dilated pupils and can help himself very much by practicing with an artificial eye. Till he does learn to relax, he can get a clear view of the fundus only by turning in front of the aperture concave lenses of three or four dioptres, which will overcome the effect of his accommodation.

It simplifies matters greatly to have the patient fix his gaze on some object directly in front and on the same level, lest he keep his eye roving from one object to another, and with the eyes in this position the light from the mirror should fall on the important structures at the back of the eyeball. If the observer does not catch sight of the nerve head at once, he can readily find it by following up the course of one of the blood vessels. In this direct method of examination the image formed in the eye of the observer is real, erect and magnified, the size of the image depending on (1) the refraction of surgeon and patient, (2) the distance between their eyes, and (3) if a glass be necessary, the distance of the glass from the eye of the patient. Calculated from emmetropic eyes without lenses, the magnification approximates fifteen diameters.

It cannot be emphasized too strongly that the student should employ every possible opportunity to examine the normal fundus, not only that he may acquire the proper facility in the use of the ophthalmoscope, but that he may familiarize himself with the numerous variations which are still within the limits of the normal, and to this end he should, to begin with at least, employ a routine method of examination which may be very profitably supplemented by attempts at drawing what he sees. This not with the idea of acquiring skill in producing fundus pictures, but of cultivating the powers of accurate observation.

The most striking feature of the fundus is the *disc,* or nerve head, or papilla, where the optic nerve and the retinal vessels enter the eye through the sclera. This is situated somewhat to the nasal side of the posterior pole and comes easily into view when the patient is looking straight before him. This opening in the sclera is not a complete one, since the inner layers of the sclera pass directly over it, forming a septum which is pierced by a number of openings for the transmission of bundles of nerve fibres, and is hence called the *lamina cribrosa.* In piercing the lamina, the fibres of the nerve lose their sheaths and become almost transparent. Hence the color of the nerve head is the glistening white of the sclera, modified by the grayish translucent fibres of the nerve, and in the centre the openings in the lamina can often be seen as small gray dots, in the midst of the lighter lamina (Fig. 46, *A*).

Commonly the head of the nerve is perfectly flat so as to lie in the same plane as the retina, but very often the fibres of the optic nerve begin to separate before reaching the level of the retina, so that a *funnel-shaped* depression is produced, from which the central vessels of the nerve emerge. This is the normal vascular funnel which may be quite extensive without being pathological, and is called the physiological excavation. (Fig. 46, *B*.) It is not to be confounded with the saucer-shaped excavation in atrophy (*C*) of the nerve or the bowl-shaped excavation in glaucoma (*D*).

A B C D

FIG. 46.

The optic nerve is not always circular in shape, but may be oval with its long diameter in either direction, and the border is formed by a delicate rim, over which the vessels run as they pass out of the excavation. Sometimes, but not always, there is running entirely around the nerve head a narrow band of white corresponding to the edge of the scleral funnel which has not been covered by chorioid. This is called the scleral ring, and at times just outside this is a ring, partial or complete, of black pigment from the chorioid, which is called the chorioidal or pigment ring.

The retinal blood vessels arise from the deepest part of the excavation and are distributed to various parts of the retina, giving off numerous branches. While there is a general uniformity in their course, there are many normal variations. As a rule there is a central artery of the retina which almost immediately on emerging from the nerve head divides into two branches, one of which runs upward and the other downward, each of these dividing near the margin of the disc into a nasal and a temporal branch. These four arteries divide and subdivide, and so supply the retina, and each is accompanied by a vein, the arrangement of veins corresponding very closely to that of the arteries. Occasionally the branching of arteries takes place in the nerve substance itself, and we have two or even four arteries instead of one, but their general distribution is unchanged. At times there is seen a small artery springing from the temporal edge of the disc and running outward. This is a branch of the ciliary artery and is known as the cilio-retinal. The arteries are to be distinguished from veins by being somewhat narrower, straighter, and in the larger vessels having a central white stripe or reflex. The smaller vessels can not be distinguished. It is to be noticed that the region of the macula to the temporal side of the disc is not traversed by any visible vessels, but is evidently richly supplied by capillaries from all the vessels which arch about it (See Fig. 31).

Pulsation can often be observed in the larger vessels, where they make sharp bends. A venous pulse is physiological and can be produced by increasing the intraocular tension by pressing with the finger. Arterial pulsation is pathological.

Though we can see the retinal vessels plainly, the retina itself is transparent and invisible except that we can sometimes see radiating from the nerve head a fine grayish glistening reticulation of nerve fibres which is soon lost in the retina. Occasionally some of these nerve fibres retain their sheaths which are opaque and appear glistening white against the red fundus. This is regularly seen in the rabbit's eye.

The rich red glow which characterizes the fundus outside the nerve head is due to the blood circulation in the numerous capillaries of the chorioid, though, as a rule, no individual vessel in the chorioid can be distinguished, since they are covered by a layer of pigment epithelium which obscures them. The amount of pigment present depends largely on the complexion of the individual. In the highly pigmented individual the spaces between the chorioidal vessels are so packed with pigment that the vessels themselves stand out by contrast as bright red striæ running everywhere and anastomosing with each other. In the albino, on the other hand, where pigment is entirely wanting, the chorioidal vessels are distinctly visible on a very pale background. The retinal vessels can be traced running over them, while the chorioidal ones are broader and deeper down, without reflexes, and by their anastomoses form a dense network.

The macula lutea, or yellow spot, is situated to the outer side of the nerve head and at a distance of about three diameters of the nerve head. The best way to see it with the ophthalmoscope is to find the outer edge of the nerve and then sweep a horizontal path with the light from the mirror till the macula is seen. This is much easier if the lamp be moved away from the patient's head at the same time, or the patient may be directed to look at the observer's ear with his other eye, during which maneuvre his macula ought to be presented directly to view. It is the most difficult part of the fundus to see distinctly because of a central corneal reflex, which long embarrasses the inexperienced observer. The macula lies in a region of great vascularity and is itself especially vascular, since it is a deeper red than the surrounding fundus. Surrounding the macula there is often a small circular ring of light, evidently a reflex, and occasionally a delicate stippling of the eye ground of the macula can be distinguished.

In every examination of the fundus, spots and areas of light are reflected from portions whose shape is suitable, and are recognized as reflexes by their peculiar glistening appearance and by their changing their shape and position with the movements of the ophthalmoscopic mirror.

The observer, having discovered no opacities in the media and having examined the eye ground, the blood vessels, the nerve head and especially the macula without finding any abnormalities, is now ready to estimate the refraction of the eye. He must bear in mind, however, that this, while a good rough test for considerable errors, is not a reliable means of estimating small ones, especially the low degrees of astigmatism which are so important from the clinical standpoint. To secure even approximately trustworthy results, the accommodation of both observer and patient must be relaxed. The best way to secure this relaxation on the part of the patient is to have him gaze at some distant object on a level with and directly in front, which has the additional advantage of keeping his eyes quiet. If allowed to fix some object near at hand, he is very apt to accommodate in proportion to its propinquity. A cycloplegic must be used, if necessary.

The rays of light reflected from the concave mirror enter the eye convergent and cross before reaching the retina, but it must be remembered that the direction of the entering rays is of no importance. The illuminated area of the retina, by diffused reflection, serves as a new source of light and therefore the direction of the emergent rays alone has to be taken into account.

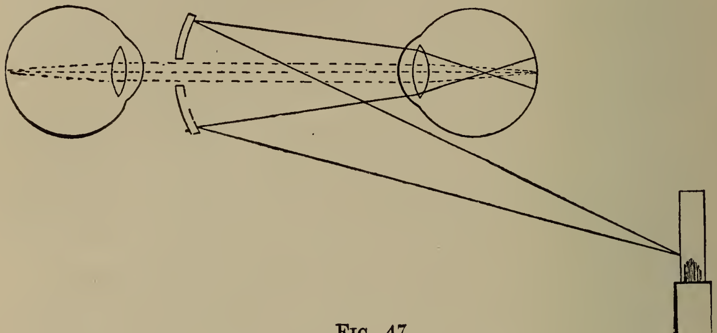


FIG. 47.

If the eye of the patient be emmetropic, the rays which come back to the observer through the aperture in his mirror must be parallel and consequently come to a focus on his retina, and he sees the fundus of the patient's eye distinctly. If, without removing the ophthalmoscope, he turns a + 1 D. lens into the aperture, the parallel rays from the patient's eye are brought to a focus in front of the retina of the physician, and he can no longer see distinctly. If, however, he turns on a — 1 D. glass, the focus is behind his retina and he can still see distinctly by accommodating 1 D. If he uses a — 2 or 3 or 4 D. glass, he can still see by using a stronger accommodation till he reaches its limit, when objects for the first time become indistinct.

Evidently, then, an eye whose fundus is distinctly visible through the aperture and becomes indistinct through the weakest convex lens, must emit parallel rays and be emmetropic.

Now suppose that the patient has a hyperopic eye in which rays of light are not refracted strongly; the rays reflected from the mirror into this eye evidently emerge divergent, and passing through the aperture tend to come to a focus behind the retina of the physician, but he exerts his accommodation enough to bring them to a focus on his retina and gets a distinct picture. If he now turns on a + 1 D. lens, it enables him to see distinctly without accommodating so much, and a + 2 D. enables him to

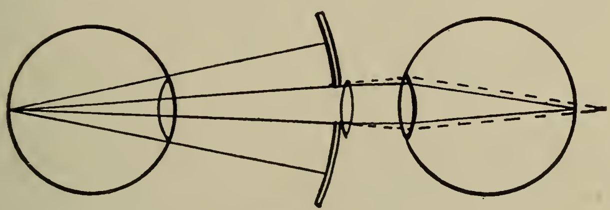


Fig. 48.

relax still further. When, however, he turns on a + 3, he can no longer see distinctly. Evidently the + 2 lens made the rays parallel and enabled him to see only by relaxing completely, while + 3 makes them convergent and brings them to a focus in front of his retina. Just as evidently it follows that the + 2 lens would enable the patient to bring parallel rays to a focus and hence is the measure of his hyperopia.

Now suppose the patient to be a myope of 3 D., from whose eye convergent rays are given off. The rays from his eye passing through the aperture in the mirror are convergent and come to a focus in front of the physician's retina, forming no distinct image. A plus glass makes them only more convergent and less distinct. A — 1 D., however, makes details somewhat plainer, and with a — 3 D.

the rays have become parallel and he gets a clear picture of the fundus. By turning on stronger concave lenses he makes the rays divergent and still sees the fundus, but only by straining his accommodation. Evidently, a — 3 D. lens made the rays parallel and is the measure of the patient's myopia.

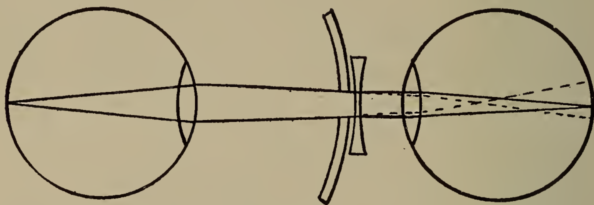


Fig. 49.

In every one of these cases it is plain that the emergent rays were made parallel by the strongest plus or weakest minus glass with which the fundus can be seen plainly, since any different glass allows the observer to use his accommodation and so is a source of error.

The macula is the portion of the retina on which rays must focus to secure distinct vision, and therefore it is theoretically the spot where we should estimate the refraction; but the various light reflexes make the macula very difficult to see plainly and a bright light on it is so dazzling to the patient that in practice we examine a spot on the same plane, but between it and the disc, and take as our test of distinct vision the ability to see clearly the velvety appearance of the retinal surface or one of the minute blood vessels which run from the disc toward the macula. If we take as our object the large vessels, their calibre is so great that their surface is in a plane far anterior to the retina, and they are visible long before and after the smaller ones are blurred; while if we take the disc, it may have such a deep excavation that its surface is far behind the retinal plane. The observer, if not emmetropic himself, must be made so by glasses or must make a corresponding correction of his ophthalmoscopic finding. For instance, if he is a hyperope of 2 D. and sees the details of the fundus best with a + 4 D. lens, it is evident that 2 D. served to correct his own error and that the patient's hyperopia instead of 4 D. is only half that amount. If the observer is myopic 2 D. he must either wear a — 2 D. lens or add 2 D. to his estimate of his patient's error.

While the beginner will find it very difficult to relax his accommodation, and for a long time will be obliged to allow a margin for error due to it, ophthalmoscopy is a fairly reliable method of estimating simple hyperopia and myopia, but when it comes to astigmatism, especially of low degree, the possibility of error becomes an actual probability. We have seen how, for practical purposes, we can consider all the refracting media of the standard eye as equivalent to a single convex spherical lens which again may be considered as composed of two convex cylinders with their axes at right angles to each other. Now, if we draw on a sheet of white paper two lines equally black, crossing each other at right angles, and regard them through a strong convex cylinder, held at its focal distance, the line which corresponds to the axis of the cylinder at once appears very much blacker and plainer than the other which is absolutely unchanged. Then, if the second cylinder is placed over the first with its axis at right angles, the other line corresponding to the axis of the second glass is brought out. Evidently each line is refracted through the cylinder whose axis corresponds to its direction.

Now, suppose an eye whose media are equivalent to a lens composed of two unequal cylinders, the one with its axis horizontal, or 180, emits parallel rays, while the vertical one, or 90, is weaker and so emits divergent rays. If near the macula of this eye we could find a vertical vessel crossing a horizontal at right angles, it is evident the vertical one depends on the cylinder whose axis is at 90 for its distinctness, while the other is seen by the one at 180.

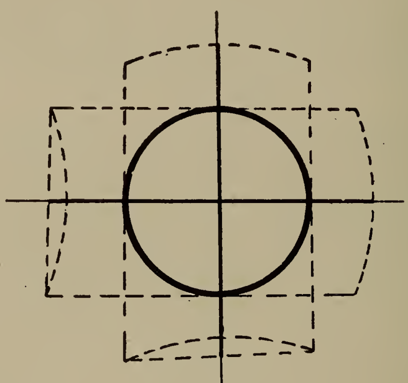


FIG. 50.

When the physician looks through the aperture of his ophthalmoscope, he is able to see the horizontal line, since rays from it emerging parallel focus exactly on his retina. Rays from the vertical line, emerging somewhat divergent, come to a focus behind his retina, and the line is not so distinct; and if he accommodates to see the latter he at once loses the former, since they focus on different planes. If he turns a + 1 D., the horizontal line (focussing in front of his retina) is blurred, so that plainly in the axis of 180 the eye is emmetropic. The vertical line is visible with a + 2 D. and blurs with anything stronger, so it is plain that the patient is hyperopic 2 D. in the axis 90 and that if he wears in front of his eye a convex cylinder of a 2 D. with the axis at 90, both meridians will be equal in their refraction and both emmetropic.

Evidently the process has been to find the strongest plus or weakest minus glass with which each of the two vessels can be seen, and the difference between them represents the amount of astigmatism. Unfortunately, we can seldom find two vessels crossing near the macula and we are obliged to take for our horizontal one of the fine vessels running from the disc toward the macula, while for the vertical we can view the extreme outer edge of the disc itself or some small vertical vessel on some other part of the field. Neither is the astigmatism always vertical or horizontal and the procedure practically is about as follows:—

If, in looking through the aperture, the fundus is plainly visible, but anything stronger than a + 2 causes the vessels running at the axis 45 to blur, while vessels at right angles or 135 are blurred by any lens stronger than + 4; evidently this patient can be made emmetropic by use of a + 2 cylinder axis 45 combined with a + 4 axis 135, which is equivalent to + 2 sph. + 2 axis 135.

In compound myopic astigmatism nothing can be distinctly seen through the aperture, but as minus lenses are turned on, one meridian clears before the other. Suppose that with a — 2 the vessels running at an axis of 75 appear distinct, while those at 165 are only clear when — 4 has been reached; evidently emmetropia can be produced only by combining — 2 ax. 75 with — 4 ax. 165 or — 2 sph. — 2 ax. 165. Or one meridian may be hyperopic, while the one at right angles is myopic.

By aid of the ophthalmoscope we can appreciate differences of level in the fundus and measure them with considerable accuracy. For instance, if the refraction of the retina is emmetropic, while a small vessel on the disc can be seen with a + 3 D., it is evident that it must be nearer the cornea, and it has been estimated that a difference of level of one-third of a millimetre causes a refractive difference of about 1 D. Similarly we can measure by the refraction the depth of the excavation or the height of an exudation, and determine from time to time whether it is increasing or not.

THE INDIRECT METHOD.—Unfortunately there are many eyes which cannot be successfully examined by the direct method. For instance, in cases of high astigmatism, while each meridian can be measured separately, it is often impossible to get any view of the fundus as a whole, owing to the great distortion. Many times it is possible to get a good idea of the fundus by the indirect method, though it has too many possibilities of error to be of value in estimating the refraction. This method requires much practice before any facility is acquired and is very commonly neglected in America, but will amply repay effort enough to master it.

The observer, when throwing the light of his ophthalmoscope into a highly myopic eye to detect opacities in the media, has probably been greatly surprised to see distinctly vessels or the optic nerve. The explanation is this:—

Just as the rays of light from a candle, after passing a convex lens, form an inverted image in front of the lens which may be caught on a screen (see Fig. 21), so the rays from the highly myopic eye, emerging convergent, form an inverted image in the air in front of the eye, which the observer looking through the aperture of his ophthalmoscope can see clearly. By the aid of a strong convex lens we can make any eye myopic and so get an inverted aërial image in front of the auxiliary lens.

The lamp is arranged as for the examination with the erect image, and the observer, sitting at a short arm's length from the patient, holds with his thumb and forefinger a large convex lens of about 15 D. in front of the patient's eye. The results are best when the lens is distant from the pupil about its focal length, or about two and a half

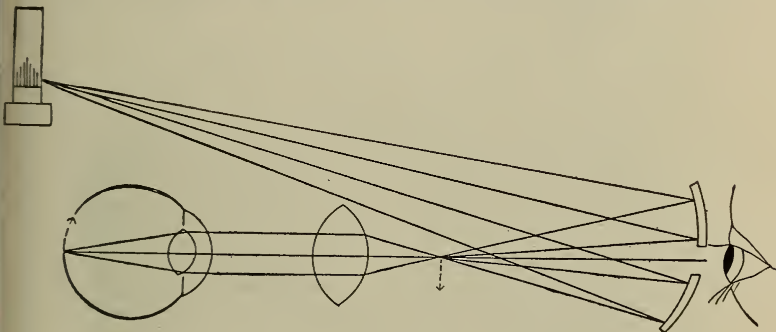


FIG. 51.

inches, and it must be held perfectly still. Both indications are met by resting the little finger on the patient's forehead and at the same time, if necessary, the patient's upper lid can be slightly raised by the ring finger without moving the position of the lens. The patient, if under atropin, should be directed to look at the student's forehead as this brings the disc and macula directly in view. When not under atropin, he should look past one's ear into the distance, lest he contract his pupil in accommodating. The light from the mirror is then thrown through the lens into the eye, and on emerging forms an aërial image of the fundus between the observer and the lens, which he can see by moving his head backward and forward in the path of light till it comes in view. This image is within a few inches of the eye and therefore seen only by accommodating. Hence it is much easier to see it by turning on a + 3 or + 4 lens, or, if one is sitting near enough to require it, a +.7.

FIG. 52.

This method shows a much larger portion of the fundus at a time than the direct, and consequently each portion of the field is magnified less. The stronger the auxiliary lens, the more extensive the field, while it is also somewhat dependent on the refraction of the eye, being larger than normal in myopia and smaller in hyperopia.

While the direct method enlarges the image from 12-16-20 diameters, according to the refraction present, the indirect with a 15 D. lens magnifies from 2-4-8 diameters.

It will be noticed at once that in moving the auxiliary lens from side to side, the fundus seems to move in the same direction, so that to get a view of the temporal side the lens is moved slightly toward the temple, or to look below the disc, the lens is moved slightly down.

By showing more of the fundus at one time and being less disturbed by errors of refraction, the indirect method may give a much better general idea of the conditions present than the direct, and should be much more generally employed than it is.

The refraction can also be measured by the indirect method, but as accuracy depends on the absolute absence of accommodation on the part of the physician, the method has fallen into disuse.

Inequalities in the eye ground are determined by moving the convex lens in front of the eye from side to side without losing sight of the disc. If the nerve be excavated, the edge will move in front of the floor in the direction in which the lens is moving. If the head of the nerve projects, its summit will move backward and forward with the movements of the lens.

The lenses which are furnished with the ophthalmoscope for use in this method are generally too small to be of much use, since the larger the lens the more emergent rays it collects and the more extensive the view. Also the presence of scratches on the lens is very objectionable, not so much because they obstruct the light as because they attract the observer's eye, and he insensibly looks at them and overlooks the aërial image between him and the lens. Consequently a large lens, protected by a very wide rim of hard rubber or metal, makes a most satisfactory lens, which can be laid down without the glass coming in contact with any surface.

CHAPTER IV.

RETINOSCOPY.

There has been considerable dispute as to the terms "Retinoscopy" and "Skiascopy," some preferring one and some the other on etymological grounds, but the two are used as equivalent terms and refer to the estimation of the refraction of the eye from a careful study of the shape and movements of a beam of light thrown from a mirror and reflected from the retina (retinoscopy) or of the so-called shadow which borders the reflex (skiascopy). When thoroughly mastered, it is by far the most generally reliable and accurate of the objective tests, since it measures not the refraction of one medium but of all, requires the simplest apparatus, and, moreover, is equally useful in young children, in the stupid and illiterate, the nystagmic and amblyopic.

The one essential to the exact estimation of the refraction of any eye with transparent media is the absence of its accommodation, which can be secured by the use of a cycloplegic like atropin or homatropin.

Retinoscopy should be done in an absolutely dark room, the light from a lamp being reflected into the eye to be examined, from a plane mirror, while the movements of the reflex are studied by the physician through a central aperture in the mirror. An electric retinoscope on the same principle as the electric ophthalmoscope, but with a plane mirror, may be used. The position of the light may be adjusted according to the preference of the observer, some having it placed on the level of and slightly behind the eye to be examined, while others place it a few inches over the patient's head. My preference is for the last, but the two chief requisites are that it shall be so placed that the light may be reflected from the mirror into the eye with as little tilting of the mirror as possible, and that no light shall reach the eye except that from the mirror, since the reflex or illumination of the retina will be much more distinct against a dark background. The closer the light is to the mirror the greater the intensity of illumination, but aside from this the distance of the light from the

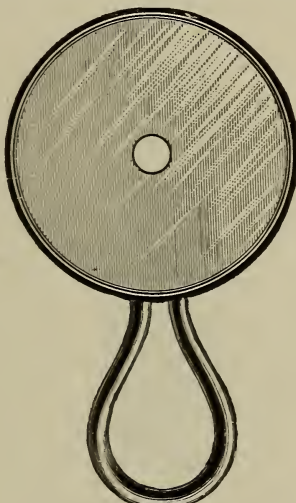


FIG. 53.

mirror is of no great importance, the only important distance being that between the eyes of the observer and observed. Neither is special apparatus for modifying or condensing the light necessary, the only requisites being that the light be bright enough to illuminate the retina and yet not so bright as to dazzle the patient. This can be secured with an ordinary candle, if necessary, or regulated as desired by the ordinary Argand gas burner or frosted incandescent bulb. If one always places the light on the side and very close, an asbestos chimney is advantageous to modify the heat, and some of them are made with an iris diaphragm to modify the light if desired. These have a certain advantage in that they do not light up the whole dark room as does the uncovered light.

The choice of a mirror is much more important. While the work was originally done with a concave mirror,

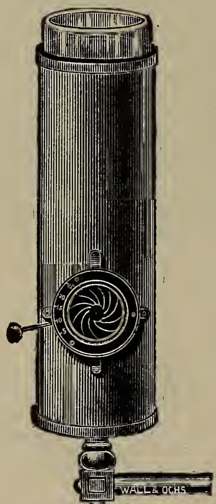


FIG. 54.

it is now the custom to use a plane one, and for fear of confusion the theory of the plane mirror only will be considered.

The essentials of a good mirror are the glass, in which all are about equally good, and the aperture, in which many are defective. The aperture is made to see through, and if it consists simply of a small area in which the silver is scraped from the mirror, it collects dirt and moisture, which are difficult to remove because of the metal backing, and are a constant source of indistinctness and annoyance. Therefore the hole should be drilled smoothly clear through the glass. Moreover half the mirrors sold have apertures entirely too small for practical use. One can see much more distinctly through the larger apertures. The refraction of the physician is of no importance, except that he must be able to see distinctly, either with or without glasses, the movements of the reflex. If he has a refractive error for which he cannot compensate, and especially if he is presbyopic, he should wear a glass which gives him sharp vision at the chosen distance. This may advantageously be fastened to the back of the retinoscope. Many a physician who has abandoned retinoscopy in disgust has done so because of an imperfect instrument or defective vision.

If we place a convex lens at its focal distance from a screen and with a mirror throw a beam of light so that it falls on one edge of the lens, and move the mirror so that the beam of light moves across the lens to the other edge, we shall see if we look behind the lens that the illumination moves in the same direction as the rotation of the mirror. Exactly the same thing occurs if we move the lens nearer or farther from the screen, except that being out of focus the illuminated area is larger and dimmer than before. Evidently, then, it makes no difference in the *actual* motion of the reflex whether the focus be in front or behind the screen; whether the eye be emmetropic, myopic or hyperopic. But if we watch the illuminated area *through* the lens, there is a decided difference, as the reflex moves with the mirror when the lens is within its focal length of the screen, and against when the lens is further away. Evidently the path of the ingoing rays may be disregarded while the emergent ones are the ones to be studied.

It is assumed that the patient's accommodation has been abolished by a cycloplegic and that the room is absolutely dark except for the light over the patient's head. In examining the right eye, the physician should be seated at a distance of one metre, should preferably place the mirror in front of his own right eye, and *vice versa.* In order that the rays emerging from the patient's eye may be as nearly macular as possible, he should be directed to look at the physician's forehead or ear or at some distant object beyond the edge of the mirror.

Now let us study for a moment the path of the rays of light and the movements of the reflex in the emmetropic eye.

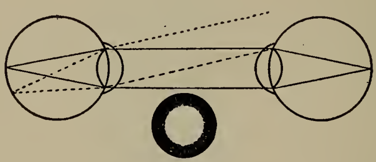


FIG. 55.

Rays of light thrown from the mirror into an emmetropic eye come to almost an exact focus on the retina and, being reflected, emerge perfectly parallel in the form of a cylinder whose diameter corresponds to the size of the pupil. The reflex in such a case, coming from a small, brightly illuminated area on the retina, is particularly bright and well defined. Now if the top of the mirror be tilted forward, so that the focus of light travels slightly downward on the patient's retina, evidently the direction of the emerging cylinder of rays will be directed upward, but as long as any of the peripheral rays reach the eye of the observer, the reflex is visible and appears to have moved lower down in the patient's eye. If the bottom of the mirror be in turn tilted forward, the focus of light travels upward on the retina, the cylinder of emergent rays is directed downward, and as long as it is visible the reflex appears to have moved upward.

The same thing holds true of lateral tilting of the mirror. But since the emergent cylinder of rays has a very small diameter, it is evident that a very slight displacement of the reflex will turn the cylinder so far that none of the rays will reach the observer's eye at all, and the reflex will at once disappear. In the examination of the emmetropic eye, therefore, the reflex is very bright and distinct, appears to move with the mirror and moves very fast, a very slight tilting of the mirror causing it to disappear. Evidently, if the pupil be thoroughly dilated, the cylinder of rays is larger and remains visible an appreciably longer time.

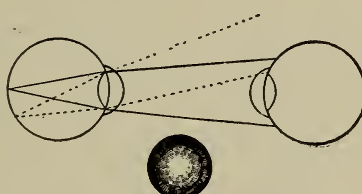


FIG. 56.

In the hyperopic eye the rays of light from the mirror tend to come to a focus behind the retina, consequently the illumination is not concentrated on a point, but forms diffusion circles on the retina depending on the amount of hyperopia. Consequently, the reflex is not as bright and distinct as in emmetropia. The rays of light emerging divergent, form a cone of light, whose base is toward the observer, and as only the central rays reach him, the reflex seems much fainter than it really is. If the top of the mirror be tilted forward, the illuminated spot on the patient's retina moves down, the cone of rays is turned upward, and it appears to the observer that the reflex has moved down with the mirror. If the bottom of the mirror be tilted forward, the illuminated area on the retina moves upward, the emergent cone is directed downward and the reflex appears to have moved upward with the mirror. The same holds true of lateral tilting of the mirror in either direction. If the rays of light be very divergent, it is evident that the mirror can be tilted considerably before the direction of the emergent cone of rays has been changed so that none of them reach the observer. Consequently, in hyperopia the reflex moves with the mirror in every meridian, and in proportion to the amount of hyperopia it is dimmer and appears to move more and more slowly.

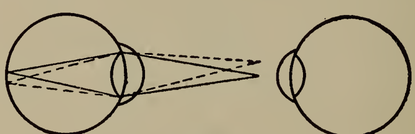


FIG. 57.

In high myopia the rays of light reflected from the mirror tend to focus in front of the patient's retina, and on the retina itself only diffusion circles form. The rays reflected from the retina emerge convergent in the form of a cone whose apex is toward the observer and crossing at the apex come to him divergent, so that only a portion of them reaches his eye. Consequently the reflex seems dim in proportion to the amount of myopia. At the apex of the cone, where the rays of light cross, an *aërial* image is formed of the illuminated area on the retina, which the observer sees instead of the area itself. Now if the top of the mirror be tilted forward, the illumination on the retina travels downward and the emergent cone of rays is directed upward, but to the observer the aërial image at the apex of the cone appears to have moved upward, or against his mirror. If the bottom of the mirror be tilted forward, the illuminated area on the retina actually moves upward, the emergent cone is directed downward, and the aërial image appears to have moved downward. The same is true of the lateral movements, and if the myopia is high, the aërial image can move through a considerable arc before disappearing from view. In myopia, then, the apparent motion of the reflex is opposite or against that of the mirror, while the reflex is dim and the motion slow in proportion to the amount of myopia.

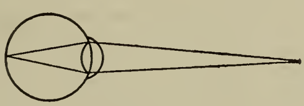


FIG. 58.

Now let us consider a very low myopia of one dioptre. Rays of light from the mirror do not form very large diffusion rings and therefore the reflex is comparatively bright. The emergent rays are slightly convergent, forming a slender cone of light whose apex is exactly forty inches from the nodal point of the eye. If, now, the observer stations himself at, say, a distance of twenty inches from the eye, or inside the crossing point of the rays, and tilts the top of his mirror forward, the illuminated area moves downward, the emergent cone is directed upward, and the observer, since he is within the crossing point of the rays, sees the reflex itself, which therefore appears to move exactly as in hyperopia and emmetropia. If he gradually increases his distance from the patient's eye, the motion continues to be with his mirror as long as he can see the reflex light itself, but the instant he gets beyond the point at forty inches, where the convergent rays cross, he ceases to see the real reflex and sees instead the aërial image, while the reflex appears at once to move against his mirror. The point where the rays cross is spoken of as the *point of reversal,* and if we can measure exactly the distance of this point from the eye, we can estimate exactly the lens required to make the emergent rays parallel. For instance, it requires a 1 dioptre lens to bring parallel rays to a focus at one metre, therefore an eye whose point of reversal is exactly one metre away converges the emergent rays just one dioptre too much. In other words, it is myopic one dioptre, and a concave glass of 1 D. will make the rays exactly parallel. If the point of reversal be established at one-half metre, the amount of myopia is two dioptres; if at ten inches, four dioptres; while, if the point of reversal was found at eighty inches, or two metres, evidently the myopia is only a half dioptre.

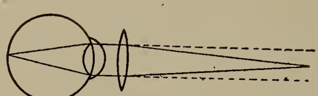


FIG. 59.

If the patient is emmetropic or hyperopic, the emerging rays of light form no natural point of reversal and we have to establish one by interposing a convex lens of known strength. If he be emmetropic, a convex lens of 1 D. will cause the emerging parallel rays to form a point of reversal at exactly one metre, a + 2 D. will establish the point of reversal at a half metre, and so on. Conversely, rays of light which after the interposition of a + 1 D. form a point of reversal at forty inches, must have been exactly parallel beforehand, and the eye must have been emmetropic. One metre is the distance usually chosen for retinoscopy as a matter of convenience, and the whole retinoscopy consists in finding the lens which, when placed before the examined eye, will cause a crossing of the rays just in front of the nodal point of the observer's eye. If, on tilting the mirror, the reflex appears rather indistinct and sluggish, and moves with the mirror, we are certain we have to do with a very hyperopic eye whose rays are divergent. We place in the trial frame before the patient's eye gradually increasing convex lenses till we find the weakest one which will cause the reflex to move against the mirror. If this is accomplished by a + 5, we remember that one dioptre of this was used in bringing the rays to a focus after they had become parallel, consequently the remaining 4 D. were just enough to make them parallel, and evidently the eye had a hyperopia of 4 dioptres.

Suppose, in another case, the reflex is very bright and moves very rapidly with the mirror, indicating probable hyperopia of very slight degree. By placing convex lenses of gradually increasing strength before the eye, we find when we reach + 1.25 that the motion first becomes against the mirror and we decide that, after deducting one dioptre for the distance at which we are working, the remaining quarter of a dioptre was all that was required to make the emerging rays parallel. Suppose again that the reflex moves with the mirror, but is reversed by a + .50 D.: evidently the rays must have been convergent a half dioptre, since, if they had been parallel, it would have required a + 1 D. to reverse the motion.

Suppose the motion is distinctly against the mirror, indicating the convergent rays of myopia, and we find that by placing before the eye a — 3 D. lens, we get a "with the mirror" motion at a metre. Evidently, if with a — 3 D. the rays come to a focus at forty inches, it will require another — 1 D. to make them parallel, and therefore, a — 4 D. is the measure of the myopia present. When we have established a point of reversal at forty inches, we have carried the process too far in hyperopia, since a dioptre less would have made the rays exactly parallel; consequently we deduct the extra dioptre.

In myopia, on the other hand, where we have established the point of reversal at forty inches, we have not carried the process far enough, and as we know that it requires another dioptre to make the rays parallel, we add that extra dioptre.

(The working distance of a metre is an arbitrary one, as we can select any distance we choose as long as we make the proper allowance. At thirty inches we should allow 1.50 D., at twenty inches 2 D., etc.)

Astigmatism.—If we think of the refracting media of the eye as equivalent to a single strong convex lens, which is again equivalent to two cylinders of equal strength, but with their axes at right angles, it follows that as long as the cylinders are equal the rays of light emerge in all meridians equally divergent or convergent or parallel, while the eye is either hyperopic, myopic or emmetropic and can be measured by the retinoscope. But if the imaginary cylinders are not exactly equal, the rays of light must be refracted more in one meridian than in the other and they no longer come to a focus at the same point; hence the name (a-stigma) (Fig. 50).

According to the strength of these imaginary cylinders the rays pass out from an illuminated point on the retina in one meridian and divergent in the other (simple hyperopia astigmatism), divergent in both, but more in one than in the other (compound hyperopic astigmatism), parallel in one and convergent in the other (simple myopic astigmatism), convergent in both, but more in one than in the other (compound myopic astigmatism), and lastly they may be divergent in one meridian and convergent in the other, in which case one meridian is hyperopic and the other myopic, and the astigmatism is called mixed.

Simple Hyperopic Astigmatism.—Imagine an eye composed of two cylinders, one with its axis horizontal, or 180°, of such strength that emergent rays refracted by it are parallel, while the vertical one at 90° is weaker and sends out divergent rays.

If the light from the retinoscopic mirror be thrown

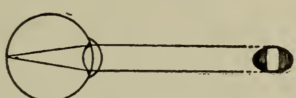


Fig. 60.

from a distance of one metre into this eye, a small area on the retina is illuminated and the rays reflected from this pass out of the eye and return to the observer. The rays in the vertical plane have been refracted by the horizontal cylinder so that they emerge parallel; and since they all reach the observer, the reflex seems to reach clear across the pupil vertically, the horizontal rays refracted by the weaker vertical cylinder are divergent, and as only the central ones reach the observer, the reflex seems much smaller and narrower horizontally. Consequently, the reflex appears to the observer to be in the shape of a bright vertical band of light which is narrower, and with straighter edges the higher the astigmatism (and the band always is exactly in line with the axis of the correcting cylinder). In simple hyperopia we saw that the rays emerged from the eye in a cone whose apex was toward the eye. In hyperopic astigmatism they form a cone whose upper and lower surfaces are flattened till they are parallel, while the sides are divergent still. If the top of the mirror be tilted forward, the illuminated area on the retina moves downward and the cone is tilted upward, but as long as any of the undermost rays reach the observer's eye, the reflex is visible and appears to have moved with the mirror; but since the cone is very narrow vertically, a very slight motion of the mirror will displace the cone so much that it is no longer visible. Consequently, the vertical motions of the reflex are with the mirror, but are very rapid. When the mirror is tilted to the right, the illuminated area on the retina travels to the right, while the cone is tilted to the left, but remains visible as long as any of the lateral rays reach the observer, and as the lateral diameter of the cone is very great, it is visible for a long time. Hence from side to side the band moves very distinctly with the mirror and much more slowly than in the vertical meridian. If we place before the eye a + 1 D. sph. and examine the vertical motion again, the rays forming the top and bottom of the cone have become convergent so that they intersect just before reaching the observer's eye, and the vertical motion is against the mirror, while the lateral motion still remains with the mirror. Since it required exactly a 1 D. lens to establish this point of reversal at a metre, we know that the rays must have been parallel before. Now, disregarding entirely the vertical motion, we add stronger and stronger convex lenses till we find the lowest one which will reverse the lateral motion which, let us suppose, requires a + 4 D. We know that one dioptre of this was required to bring the rays to a focus after they were parallel, and the remaining three must have been sufficient to make them exactly parallel. If we substitute a + 3 cylinder axis 90, so as to correct only the divergent rays, all the light reflected from the eye will emerge in parallel rays, and by the addition of a + 1 sph. the motion will be reversed in all meridians exactly as in emmetropia.

In COMPOUND HYPEROPIC ASTIGMATISM the rays of light emerge divergent in both meridians, but more so in one than in the other.

They therefore form a somewhat flattened cone of rays, only the central ones reaching the observer's eye. In the meridian nearest the normal, fewer rays reach the eye than in emmetropia, so the reflex still has the appearance of a band which is at right angles to the more divergent rays and therefore indicates exactly the axis of the correcting glass; but the band is not as well defined as in simple astigmatism and in high grades is very difficult to see, but becomes more and more distinct as we get our meridian corrected. Since all the rays are divergent, the reflex moves with the mirror in all directions, but more slowly in the meridian of greatest divergence. Let us suppose that by adding stronger and stronger convex lenses a band of light gradually develops pointing toward the axis 45 on the trial frame, and that when we have reached a + 3 D. sph. the up-and-down motion is reversed; it is evident that the meridian would be made emmetropic by a + 2 cyl. axis 135. Passing on to the lateral motion of the reflex, we find that reversed by a + 5, and evidently this meridian is made emmetropic by a + 4 cyl. axis 45.

The eye as a whole, then, would be made emmetropic by a combination of a + 2 ax. 135, with a + 4 ax. 45, which is equivalent to + 2 sph. ⌒ + 2 ax. 45. We should be able to prove this result by demonstrating a point of reversal at one metre with a + 1 D. in all meridians.

We get the same result, if we consider the lens which corrects the least ametropic meridian as the measure of hyperopia while the difference between this and the glass which neutralizes the other meridian represents the astigmatism corrected by a cylinder with its axis corresponding to the band.

Simple Myopic Astigmatism.—In this condition rays of light emerge parallel in one meridian and convergent in the one at right angles to it; consequently, the rays form a flattened cone, just as in simple hyperopic astigmatism,

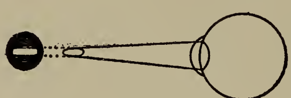


Fig. 61.

except that the apex instead of the base is directed toward the observer. If the rays forming the sides of the cone emerge parallel, the reflex will appear to reach clear across the pupil, while in the meridian at right angles, where the rays are either convergent or divergent according to whether the observer is within or without the point of reversal, the reflex is much narrower. Therefore, in myopic astigmatism the rule holds good that the band of light in the pupil lies in the axis of greatest ametropia and therefore indicates the axis of the correcting glass. In the case supposed then, there will be a bright reflex band running horizontally across the pupil.

Lateral tilting of the mirror will cause the reflex to move with the mirror from side to side and the motion will be reversed by a + 1 D. sph. at forty inches. Vertical tilting on the other hand will cause the reflex to move up and down against the mirror since the rays cross before reaching the eye and form an aërial image of the reflex. If they cross exactly at forty inches, the patient must be myopic exactly one dioptre in that meridian, since a lens of that strength would be required to make the rays parallel. If it requires a — 2 D. to reverse the motion, the astigmatism must be — 3, since, as in simple myopia, if — 2 brings the point of reversal to forty inches, it will require another dioptre to make the rays parallel. Evidently by placing before the eye a — 3 D. cyl. ax. 180, the eye will be made emmetropic in all meridians, which can be proven as in the other cases. In astigmatism as in simple myopia, if the error be less than 1 D., the motion of the reflex will be with the mirror, but will be reversed by a weak convex lens, and the correction should be estimated exactly as in myopia, but in one meridian at a time.

In Compound Myopic Astigmatism the rays of light are convergent in all meridians, but more so in one than in the other. In such a case the motion will be "against" in both, and each meridian must be estimated separately. If the motion of the reflex is reversed by — 2 in one meridian and by — 4 in the other, there is evidently 2 D. of astigmatism, while to the myopia of — 2 sph. must be added a dioptre for the distance at which we are working, so that the eye would be made emmetropic by a — 3 ○ — 2 cyl.

The correction in mixed astigmatism is estimated in the same way. The light in one meridian passes from the eye in convergent rays, while that in the other is divergent; consequently the reflex moves with the mirror in one and against in the other. Each should be estimated separately, adding one dioptre to the minus glass and subtracting one from the plus. The correcting glass is estimated by combining the two.

If the vertical reflex is with the mirror and reversed by a + 2, the refraction in that meridian is + 1 axis 180, and if the lateral motion is against the mirror and reversed by — 2, the refraction in that meridian would be — 3 axis 90, and the two may be combined in either of three ways:

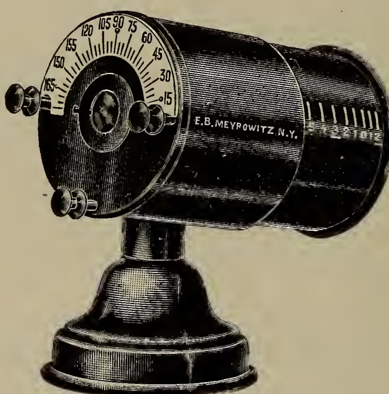


FIG. 62.

(+ 1 ax. 180 ⊃ — 3 ax. 90), (— 3 sph. ⊃ + 4 ax. 180), (+ 1 ⊃ — 4 axis 90).

Retinoscopy is by far the most generally useful and accurate method of estimating the refraction of an eye, and with comparatively little practice the beginner can make an approximate estimate of the conditions present. But the determination of the exact point of reversal, the exact axis of astigmatism, in other words, the estimation of refraction to the fraction of a dioptre which is advisable in many cases, is a much more difficult matter. For this reason the student is strongly advised to purchase one of the artificial eyes on the market and practice assiduously (Fig. 62). By aid of one of these he can artificially create an eye with any variety of ametropia and study the movement of the reflex and the adjustment of suitable lenses. It is very probable that some persons have a special aptitude for the method, because of keen sight, and then there are many others who never become very accurate through a defective faculty of observation.

In some cases the method is not applicable at all, especially when opacities in the cornea and lens so scatter the emergent rays that the motion of the reflex cannot be distinguished with certainty.

FIG. 63.

Spherical aberration is also a great puzzle to the beginner, especially when the pupil is dilated widely. In simple hyperopia, for instance, of low degree, the rays in the centre of the reflex come out divergent and cause a "with" motion of the reflex. But the peripheral rays are refracted more strongly, come out convergent and move against the mirror. The reflex in such a pupil appears in the form of a peripheral ring of light moving against the mirror with a central area moving with it. As stronger and stronger lenses are placed before the eye, the "with" reflex gets smaller and more rapid as the point of reversal is approached, while the peripheral ring gets broader and more distinct in proportion. But the peripheral refraction is of no importance to the patient, because these rays are ordinarily cut off by the iris, and the centre of the reflex alone should be the guide. Evidently if the observer is not very careful and sharp-sighted, he will overlook the faint central "with" motion and underestimate the hyperopia. In myopia the peripheral refraction is also greater than the central, and as concave lenses are placed before the eye, the motion of the centre of the reflex is reversed and becomes "with" sooner than the peripheral circular reflex. If one keeps adding concave lenses till he has reversed the more conspicuous reflex, he has evidently overestimated the amount of myopia, which is often a serious mistake.

When the spherical aberration is negative, as in conical cornea, the central rays are refracted more strongly than the peripheral and the conditions are reversed. If the student will bear in mind that from the standpoint of distinct vision the centre of the pupil is the important part, and be guided only by the motion of the centre of the reflex, he will soon cease to be troubled, and some day we may discover a drug which will paralyze the ciliary muscle without the troublesome dilation of the pupil.

This same spherical aberration is the source of great trouble in estimating astigmatism. At the axis, 180 for instance, we have seen that the round reflex becomes a horizontal band. The peripheral ring is also elongated in the same direction, very often to such an extent that only the top and bottom are visible. We therefore have three bands across the pupil, and, as the peripheral ones move more slowly, the central one appears to overtake first one and then the other as the mirror is moved. As the point of reversal is approached, the peripheral bands move "against" before the central one.

If the horizontal plane of the eye is not exactly on the same plane as that of the observer, but is turned slightly up or down, one of the peripheral bands is not seen and there are left only two which approach each other and recede like the blades of a pair of scissors. Theoretically, the same phenomena should be observed in astigmatism with the axis vertical, but practically it is not as noticeable, probably because—as we shall see in another chapter—we have much more practice in discriminating vertical lines than horizontal, from the prevailing shapes of our alphabet. Some authorities ascribe this scissors reflex to a tipping of the crystalline lens slightly forward or backward in its fossa. The scissors reflex clinically, therefore, almost always means a hyperopic astigmatism axis horizontal, and to estimate it correctly one must disregard the peripheral rays entirely and study only the central ones. Here, as in simple hyperopia and myopia, the danger is of underestimating the first and overestimating the last.

Retinoscopy Without a Cycloplegic.—Since retinoscopy depends entirely for its accuracy on a complete relaxation of the ciliary muscle, it might be supposed that the method was useless except under cycloplegia. To a certain extent this is true, but after some practice the method will be found very valuable in many cases which are not under atropin. As we have already seen, there is a large class of patients in which a cycloplegic is not desirable, either because it is inconvenient or because, since they come for improvement of vision and not for relief of strain, a full correction is neither necessary nor even desirable.

When under atropin, the patient is directed to look at the observer's forehead or ear during the process of retinoscopy. If he is not under atropin, he will at this distance be accommodating a dioptre, and if he is hyperopic, very much more, but if he be directed to gaze past the observer's ear into the obscurity of the dark room which is particularly arranged so that there shall be nothing to fix his attention, his accommodation will be in a state of physiological relaxation which is often almost as great as in cycloplegia, and with the manifest advantage that the moderately contracted pupil shuts out the peripheral rays which are so troublesome.

The working distance should be one metre, and if the observer does not carry the correction quite to the point of reversal, but only finds the glass with which the original motion of the reflex is no longer perceptible, this will very closely approximate the actual refraction without adding 1 D. in myopia or subtracting 1 D. in hyperopia. Any motion "with" the mirror *certainly* means hyperopia more or less, while any motion "against" the mirror only *probably* means myopia.

By examination of a long series of patients by both methods, the writer has convinced himself of the usefulness and accuracy of the method when used in connection with other tests. It is the commonly accepted theory of accommodation, whether invariably true or not, that the ciliary muscle contracts and expands equally in all meridians and that the lens is, in health, equally elastic in all meridians. Under these conditions, even if the relaxation be not complete, the error will be the same in all meridians, and so the difference between meridians which represents the amount of astigmatism will be a constant one and the same as under cycloplegia. Thus, as we shall see, astigmatism is generally due to optical defects in the cornea rather than the lens, which we can estimate with approximate accuracy by another method, and the two serve as checks on each other. The tendency in retinoscopy without cycloplegia is certainly to overestimate myopia, but it becomes less and less as proficiency increases with practice. It certainly is not a scientifically exact method of estimating the total refraction, nor is it dependable in very young and unintelligent patients, but as a rapid method of determining errors of refraction at the first visit it is very useful, and in the very large class of patients who simply

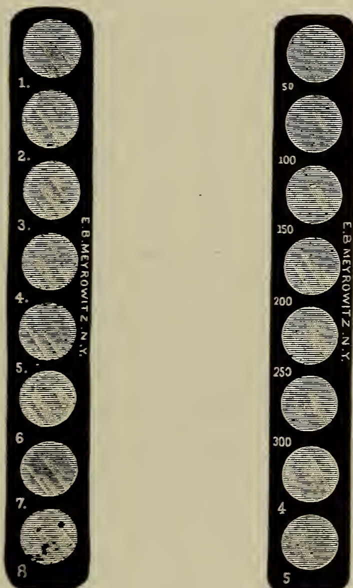


FIG. 64.

want glasses to improve vision and not to relieve strain and who would certainly be very much disgusted with a full correction, it is, in conjunction with other tests, entirely sufficient.

In retinoscopy it is the custom to place a trial frame on the patient and use appropriate lenses from the trial case in estimating the refraction. This has the advantage of permitting a very exact measurement of the error owing to the many fractions of a dioptre contained in the case.

In estimating astigmatism some surgeons make use of cylinders, but it is not usual, since it is just as easy to use spherical lenses, neutralizing the meridians of greatest and least curvature separately. For clinical convenience the writer devised a series of lenses set in hard rubber frames which are small enough to be carried in the vest pocket, and which contain graduations enough to meet the requirements of ordinary clinical work, though of course they would not suffice where extreme accuracy was desirable. They can be held by the patient before the eye, but it is much easier and more rapid for the physician to hold the frame against the patient's eyebrow himself. Of course, this reduces the working distance between the lens and mirror materially, for which due allowance must be made. In the ordinary case this is about thirty inches, calling for a correction of a dioptre and a half, instead of the customary one dioptre. He has found it a very great convenience, not only in clinical work, but in the preliminary examination of private patients, where it is often desirable to know approximately the amount of error present in persons who have called for some other difficulty.

CHAPTER V.

THE PUPIL—CYCLOPLEGICS—MIOTICS—STATIC REFRACTION.

We have alluded very briefly to the physical effects which occur in the iris and lens during the change of focus from the far point to the near, but have made no explanation of the nervous mechanism by which they are controlled; indeed, the changes themselves are not by any means simple or well understood. We have seen that the iris is largely composed of blood vessels, that it has a sphincter, by stimulation of which the pupil is narrowed, and that it contains elastic tissue which contracts when the sphincter relaxes, and dilates the pupil, not widely but moderately, till a balance is obtained between the tonicity of the sphincter and the elastic fibres. The contraction of the sphincter takes place under the influence of a branch of the third nerve, running from the anterior part of the floor of the fourth ventricle very close to the allied third nerve nuclei, for accommodation and convergence. This contraction takes place when the retina is exposed to light in proportion to the sensitiveness of the retina and the brightness of the light. The stimulation reaches the optic tract through the optic nerves and is carried to the oculomotor nucleus by a special set of communicating fibres, and because of the decussation of optic nerve fibres both pupils respond to stimulation of either retina. Pupillary contraction also occurs automatically with convergence and accommodation, all this being governed by closely associated nuclei of the same nerve. It also occurs when the aqueous is deficient, which explains why the pupil cannot be dilated with an open wound in the anterior chamber. It also occurs upon the administration of certain drugs such as eserin, morphin, in epileptic attacks, etc., and in certain nervous diseases. Conversely, dilation of the pupil occurs when the contractile stimulus is diminished by darkness. When the eye is focussed for distant objects with corresponding relaxation of accommodation and convergence, the pupil also relaxes and is semi-dilated. This also occurs when its aqueous humor is abnormally abundant with a consequent increase in tension, as in glaucoma, during fatigue, during the administration of certain drugs, in certain nervous diseases and as the result of emotions. The impulses from the cervical sympathetic seem to play an important part in the dilation of the pupil, not only by inhibiting the action of the sphincter, but also by a specific dilating action of their own. Entirely aside from the action of the elastic fibres in the iris, the pupil seems then to be under the influence of two antagonistic forces: that of the third nerve which, under appropriate stimulation contracts the pupil and when not acting permits moderate dilation, and that of the cervical sympathetic which, when stimulated, not only inhibits the sphincter action, but causes a wide dilation such as occurs under the influence of fear, anger, etc. Section of the sympathetic in turn not only removes the dilating influence, but removes the only restraint on the action of the sphincter and hence results in a marked contraction of the pupils. According to this theory the excision of the sympathetic ganglia in the neck has been practiced with the idea of narrowing the pupil in glaucoma.

The effect of many drugs seems to be wholly or in part independent of these nerve influences. For instance, atropin causes a wide dilation of the pupil and eserin a corresponding contraction, but both are said to produce their full effect after the division of all the nerves and even after extirpation of the eyeball. They appear to act directly on the muscular tissue of the sphincter or on its nerve endings, and hence their action is entirely local. Other drugs apparently affect the pupil partly or wholly by their action on the blood vessels of the iris. For instance, cocaine causes an iritic ischemia and tends to dilate the pupil by stimulating the sympathetic, and though it has no cycloplegic action of itself, is often added to cycloplegics to accomplish this very purpose. Dionin, on the other hand, partly, perhaps, by its lymphagogue reduction of tension, but chiefly by a temporary edema of the iris, will sometimes contract a pupil that has been paralyzed by atropin.

As the result of the crossing of the fibres of the optic nerves so that filaments from each eye reach both oculomotor nuclei, both pupils in health react together to stimulation of either retina, and therefore should be practically equal. Any inequality (anisocoria) is pathological and must be due not to perceptive anesthesia, but to some interference with the innervation of the sphincter. It may be caused by conditions in the iris itself, such as adhesions between the margin of the pupil and the lens, which prevent entirely or in part either contraction or dilation, or by traumatism by which the sphincter is temporarily paralyzed, and this paralysis frequently involves only a portion of the fibres so that the pupil is oval or irregular. It may be caused by an increase in the tension of one eye, as in simple glaucoma, as well as the frequent accidental poisoning by infinitesimal doses of atropin, and this should be constantly in the clinician's mind. It is often caused by paralysis of the third nerve, occasionally alone, but generally associated with paralysis of accommodation and some of the extrinsic muscles, and may be a valuable guide to the localization of cerebral lesions. An anisocoria may also be caused by the sympathetic nerves, either an undue irritation on one side causing unilateral dilation, or paralysis causing contraction.

The size of the pupils varies widely even in health, being much greater in youth, in conditions of anemia and malnutrition and in refractive anomalies, through which there is present a certain amount of retinal anesthesia, and the sphincter of the iris often partakes in the exhaustion of the ciliary muscle. In older patients smaller pupils are the rule and in the very aged the blood vessels become hardened, the iris inelastic and an actual miosis (extreme contraction) is present. Scales are provided for measuring and recording the diameter of the pupils in millimetres, when this is desirable.

The reaction to light should always be tested, the best method being that described in the chapter on ophthalmoscopy, the direct method giving us a view of the pupil magnified by a 7 D. lens, while by arranging the light behind the plane of the patient's eye we can change the illumination instantly from practical darkness to that of the condensed light from a concave mirror. For the consensual reaction it is necessary to use daylight or have the light so arranged that both pupils are visible without being strongly illuminated, where the light can be condensed on one with a lens, while the other is carefully watched.

The reaction to light is generally a very good and very delicate test of the perception of light, but it is not to be forgotten that there are a number of conditions in which the reaction may fail though the perception is normal. This would occur in the conditions already alluded to, but unless the other eye were also affected, the consensual reaction would answer the same purpose. For instance, in locomotor ataxia the reflex arc connecting the optic nerve with the nucleus of the third nerve is interrupted on both sides. As a result neither pupil contracts to light stimulation of the retina, but the third nerve itself being unaffected, the pupil reacts as usual during accommodation and convergence. This is the Argyle-Robertson pupil. In these nervous conditions a very marked contraction of the pupil known as *spinal miosis* is often present. Conversely there are patients whose reacting pupils show that the eyes see, but who are brain blind, as for instance in some cerebral hemorrhages, uræmias and hysterias.

A cycloplegic is a drug which will, for the time being, paralyze the ciliary muscle and prevent the use of the accommodation, while a *mydriatic* is one which has the power of dilating the pupil and may or may not have any effect on the ciliary muscle. The cycloplegics all have a mydriatic action, but not all mydriatics are cycloplegics. The two words are very commonly, though incorrectly, used as though both implied paralysis of accommodation.

Atropin and hematropin are the drugs most commonly employed, but there are a number of others less popular, but useful. The following table shows the duration of the paralysis from the different drugs which will be noticed to vary widely:—

	Complete Paralysis	Complete Recovery
Atropin	4 days	15 days
Homatropin	12 hours	2 days
Scopolamin	12 hours	6 days
Hyoscyamin	3 days	8 days
Duboisin	2 days	8 days

If a solution of appropriate strength is dropped into the eye, it is in the course of a few minutes absorbed by the conjunctival vessels and penetrates the anterior chamber so that it acts directly on the nerves of the ciliary body and the iris, causing paralysis first of the latter, as shown by the dilated pupil, and soon afterward of the other, as shown by a growing inability to see distinctly close at hand. Unless very carelessly used, there should be no systemic effect from these instillations, but sometimes the solutions, if used too freely, are carried through the lachrymal passages to the nose and throat and so produce by absorption a dry throat, flushed face and a rapid pulse, in fact, all the effects of a mild belladonna poisoning. To prevent this possibility, it is well to have the patient make pressure over the punctum at the inner corner of the eye for a couple of minutes with his finger or a pledget of cotton. Occasionally patients have an idiosyncrasy against these drugs which cause a severe conjunctivitis of the follicular type. The tendency to conjunctivitis and dermatitis can be much lessened by combining with the cycloplegic an astringent, like zinc sulphate, in the strength of one grain to the ounce. Solutions of atropin in oil, like castor or olive, are often much more effective than aqueous ones. Oily solutions must be made with the alkaloid and not the salts of atropin which are not soluble.

Patients should always be warned of the expected effect of the drug on vision, since otherwise they are often very much alarmed at the inability to see things near at hand. Cycloplegics should never be used when there is the least suspicion of a tendency to glaucoma, since there are many cases on record where acute attacks have been precipitated by their use, and the stronger ones are to be avoided in the case of nursing women, lest they accidentally absorb enough to influence the mammary secretion.

Indications for Cycloplegics.—Whether the use of cycloplegics should be a routine one or not, has been—and probably always will be—a subject of dispute among ophthalmologists, one school claiming that no scientific refraction is possible without, and the other that their use is rarely necessary. So bitter has been the controversy and so positive have been the assertions on the subject that the whole profession to-day has a vague impression that, on the one hand, an ophthalmologist who does not regularly use a cycloplegic has not done his full duty by his patient, and on the other hand, that if an examination under a cycloplegic does not relieve the symptoms the eyes cannot be at fault.

A moment's thought will convince one that while there is, without doubt, a foundation for both beliefs, neither one is unreservedly true. The one advantage of a cycloplegic is that it paralyzes the accommodation, and it has associated with it the obvious disadvantages of dilating the pupil widely and so calling into use the peripheral portions of the refracting media which nature evidently did not intend should be used for this purpose. Its use is always a source of discomfort and often of alarm to patients and has contributed as much as anything to the vogue of the refracting optician who is not permitted to use drugs and widely urges that they are never necessary.

To me it seems that the use of a cycloplegic is an individual question depending on two personal equations: those of the physician and his patient. The physician who has fallen into the habit of always using a cycloplegic, depending on his retinoscopic tests without the careful use of the ophthalmoscope, ophthalmometer and other auxiliary tests, is utterly lost when it comes to the examination of an eye when the pupil is small and the accommodation active, and thinks everyone else must be equally at sea, while as a matter of fact, an experienced man using care and judgment will, *in suitable cases,* reach the same result either with or without a cycloplegic. In elderly people, whose accommodation is no longer active, a cycloplegic is seldom necessary. On the other hand, in the very young, the ignorant, the nervous, and especially in those cases where there is a spasm of accommodation, no very trustworthy result can be obtained without a cycloplegic. The purpose of the examination also is very important in arriving at a decision. There is a very large class of patients who come with no discoverable symptoms except poor vision due to presbyopia, hyperopia, astigmatism, etc. In these it is a matter of minor importance whether the entire error be corrected, as long as a partial correction gives the desired keenness of vision. Indeed it commonly happens that a full correction under atropin is very much less satisfactory to these patients than a partial one. In myopia and astigmatism, where there is much greater danger of over-correcting the error and so producing accommodation strain, greater care is necessary and much more frequently the use of a cycloplegic, but in young, vigorous patients the over-correction is not necessarily harmful.

There is another large and increasing class of patients whose vision may be perfectly good, who consult the oculist because of headache, chorea, double vision, or who come to have the eyes, as possible causes of various reflexes, excluded. In such cases it is desirable to be absolutely accurate in the estimation of refraction, and a cycloplegic is certainly called for. Between these two extremes come a series of cases where the employment or non-employment of a cycloplegic is a matter of individual judgment and skill.

The choice of a cycloplegic is also a matter of importance, since it is better to use none at all than to imagine the accommodation is paralyzed when it is not. Atropin is the oldest and perhaps the most efficient of our drugs, and yet occasionally we see cases in which even prolonged use does not cause complete relaxation, while with homatropin and the weaker cycloplegics, I am convinced that many oculists are in the habit of estimating the refraction of patients, who, while they have a widely dilated pupil, are but partially under the influence of the drug.

In the selection of a cycloplegic the physician must be guided by the patient's age, occupation, the nature of his difficulty and the kind of refractive error present. For practical purposes all the cycloplegics may be divided into two classes: one, of which atropin stands at the head, in which the cycloplegia is complete and lasts many days, and the other represented by homatropin in which the drug is not as powerful and its effect evanescent.

An elderly person in whom the accommodation has become inactive, if indeed any cycloplegic is necessary, could use homatropin, while in a child with a very active accommodation the same drug would be entirely untrustworthy. A busy man cannot afford to use atropin which will certainly keep him from his work at least a week, while he might be able to use homatropin at the week's end with the certainty that he would be able to use his eyes by the beginning of another week. A patient whose tired eyes are giving rise to reflex symptoms should be examined under atropin, since there is more likelihood of discovering his total error, and also because he will actually benefit from the long rest.

The same may be said of myopic eyes in which there is a tendency to spasm of the accommodation which only yields to a strong cycloplegic, and in which there is very often chorioidal change which is benefited by the enforced rest. It is fortunate that in high myopia the cycloplegics cause much less disturbance of vision, since the myopic pupil is large normally, and the patient is not dazzled by the increase in its size and can still see things near at hand, because he is myopic.

Commonly, when ordering a cycloplegic, the patient should be directed to wear temporarily a smoked glass to avoid the unpleasant dazzling.

Atropin should be used in a one-per-cent. solution, one drop being instilled into each eye three times a day. These drugs can be obtained in the form of gelatin ophthalmic discs of corresponding dose, which are allowed to dissolve in the eyes.

I have expressed a decided distrust of homatropin, as it is commonly used, but if used freely enough, a satisfactory cycloplegia may be obtained in suitable cases. It should be prescribed in very small quantity, as it is very expensive, the patient being directed to instill a drop of two-per-cent solution several times a day during the day prior to examination. If used in the office a drop is instilled every five minutes for half an hour, or one of the gelatin discs allowed to dissolve in the eye, but it is important to remember that it requires at least an hour for the full cycloplegia to develop.

This method sometimes causes a blood-shot eye, and while it dilates the pupil, the completeness of cycloplegia is open to doubt, since it has been demonstrated that in some cases only a partial paralysis occurs. One portion of the ciliary muscle is at rest while another is still active or even in a state of cramp, thus causing the appearance of a pseudo-astigmatism which is not normally present.

Cocaine is very commonly combined with homatropin, both in the solutions and in the ophthalmic discs, and it certainly *appears* to increase the effect, but cocaine has no paralyzing action on the ciliary muscle and probably only increases the dilation of the pupil which is a positive disadvantage, while it also, in many cases, causes temporary changes in the epithelium of the cornea which appears hazy and embarrasses the physician in his retinoscopy and the patient at the test cards. Another disadvantage of homatropin is this, that in patients who for various reasons should wear the entire correction of their error, the effect of the drug passes off before they have even got their glasses, and hence, when they are put on, the patient cannot see through them, while atropin passes off so slowly that the effect of the drug is insensibly replaced by that of the glass.

On the whole my advice to beginners, at least, is to *learn* to get along without a cycloplegic as much as possible, by methods which will be described, but when one is necessary, select one which shall be thorough and have it used long enough before the examination so that the result shall be final and conclusive. The weaker drugs should be reserved for patients who cannot be satisfactorily examined without a cycloplegic and yet cannot spend the time necessary for one of the slower and stronger remedies.

When cycloplegia is complete the patient is entirely without focussing power. With a suitable convex lens for instance, he can still read fine print or see the hairs in the hair-optometer, but they are distinct only at a fixed distance and become blurred when brought either nearer or further from the eyes.

We have reason to suppose that the accommodation is not completely at rest when there is a notable difference between subjective and objective tests. For instance, a patient who can still read his newspaper cannot be under the influence, unless he be naturally myopic. A patient who, by retinoscopy, has shown a hyperopia of 3 D. and yet by the test cards reads 20/20 with a + 1 D. must be using his accommodation. A patient who makes no expression of preference between a + 1, + 2 or + 3, the vision being equally clear with all, must be accommodating. A patient whose objective myopia is — 2 and yet who prefers — 5 in the subjective tests, must be accommodating. On the other hand, a patient whose dark room test shows myopia, while at the test cards he reads 20/20 without glasses, was evidently accommodating during retinoscopy. In other words, a patient ought to obtain the best vision with a glass approximately equal to the dark room correction, and any discrepancy throws suspicion on the accuracy of the examination or the completeness of the cycloplegia.

Static Refraction.—We have already seen that in the emmetropic eye, parallel rays of light come to a focus on the retina without any effort on the part of the patient.

In the short or hyperopic eye they tend to focus behind the retina and clear vision is only secured by contraction of the ciliary muscle. In the myopic or long eyeball, the rays focus in front of the retina, and clear vision is only secured by bringing the object of regard nearer, till the rays do impinge on the retina. In astigmatism clear vision is secured, if at all, by one or the other of these methods, or by a combination of the two. All varieties of ametropia, therefore, mean either a reduction of distant vision or the imposition of abnormal muscular effort in seeing distinctly.

The static refraction of an eye means the estimation of the glass or combination of glasses which shall enable it to focus parallel rays on its retina when the accommodation is completely relaxed by a cycloplegic.

In the estimation of this total error the subjective or trial case method is to be considered as the court of last resort. In young children, idiots, and illiterates, we are compelled to rely on other tests, and with skill can make a very close approximation to the truth, but with an intelligent patient the subjective method is decidedly more delicate.

Of the objective methods, the ophthalmoscope is hardly to be considered a refractive instrument except of the roughest sort. The ophthalmometer, as we shall see, estimates only the astigmatism of the cornea and is not claimed to be accurate within a half dioptre. The retinoscope furnishes our most reliable objective test, but with it we study the course of rays which emanate from a comparatively large region about the macula, while distinct vision depends on the macula alone, whose minute bundle of rays may have a distinct refraction of their own. The patient is the only one who can tell with the utmost delicacy whether rays focus exactly on his macula, because this gives him the clearest possible vision, and he can very often distinguish differences of an eighth of a dioptre or of two or three degrees in the axis of a cylinder. It must be remembered, too, that the static refraction does not mean the strongest plus or weakest minus combination which gives the patient normal vision, but the combination of any nature that gives him the greatest possible visual acuity, since his accommodation is paralyzed, and it is not necessary to make any allowance for strain.

Before using a cycloplegic it is advisible to make a routine examination of the eye which should give an approximate idea of the refraction as well as reveal any disease present. At the same time the distant vision both with and without glasses should be noted. In estimating this vision we not only measure the refraction but determine the delicacy of the retina, regardless of muscular strain, so that we may have some standard of vision to be attained or surpassed after the induction of cycloplegia.

One of the most essential requisites of good refraction is a good trial frame, one strong and rigid enough to remain squarely and firmly on the nose and in which the lenses can be so adjusted that their optical centres are opposite the middle of the pupil, perpendicular to the visual line and at the same distance from the eye at which it is intended the correcting lenses shall be finally worn, viz., just as close to the cornea as they can be without being swept by the eyelashes. We now seat the patient before the test card and, examining each eye separately, note his vision without glasses and thus, guided somewhat by our retinoscopic examination, place spherical lenses in the frame in gradually increasing strength so long as the vision continues to improve. When this point has been reached we resort to cylinders, beginning with weak ones and, if they are of advantage, increasing till the maximum vision is reached. In determining the axis of the cylinder, it is best to accept not the one indicated by the retinoscope or ophthalmometer, but that which gives the clearest vision, turning it a few degrees in either direction to be certain that the patient always prefers one definite axis. If he seems uncertain, the cylinder should be rotated first one way and then the other, noting carefully the exact points where the patient is conscious of indistinctness. The point half way between may be assumed as the meridian of sharpest vision. To be sure that one has the combination giving the maximum acuity it is best to make experiment with spheres and cylinders, both slightly stronger and weaker, but the final selection ought to be one which is blurred by the superposition of the weakest lens of whatever sort. This can be conveniently done by placing over the correction a so-called "cross cylinder," a weak plus cylinder ground at right angles to a weak minus one, thus at the same time increasing one meridian and diminishing the other one. In these tests it is best to be guided not so much by what the patient says as by the accuracy with which he reads the letters on the trial cards which should be changed from time to time as he becomes familiar with them.

The determination of the static refraction does not mean that we necessarily prescribe the full correction for the patient to wear. The final prescription will depend on various factors, such as the age and occupation of the patient, the symptoms from which he is suffering and the amount and character of his error.

When patients complain simply of defective vision it is very seldom necessary to subject them to cycloplegia, since the object can be as well, and often better, accomplished without it. In myopia and myopic astigmatism we frequently use cycloplegics to avoid over-correction and consequent strain. In these conditions it is customary to give the full atropin correction at once unless the error is an extreme one, in which the glass might possibly cause discomfort if worn for the first time.

In patients with reflex symptoms, such as headache, we correct all or nearly all the astigmatism and as much of the hyperopia as, in our judgment, the patient can stand without discomfort. If he is young he has a stronger accommodation and will be restive under a correction which in middle life is easily born. If the symptoms are more serious, as in migraine, strabismus and the like, or the case is one in which the object is to exclude the eyes as a factor in some reflex condition, it is advisable to order the full correction for constant wear, and if necessary keep up a moderate cycloplegia till the patient's accommodation becomes relaxed enough to permit it.

Miotics.—Eserin and pilocarpin have an action opposite to that of the cycloplegics in that they place both the sphincter of the iris and the ciliary muscle in a state of tonic contraction. Consequently the pupil becomes very small and the eye is in a constant condition of accommodation. When strong solutions are used, eserin often produces a feeling of tension in the eye with headache and sometimes nausea. The action of the miotics is of shorter duration than that of the cycloplegics and is less powerful, and their application in diseases of the eye does not fall within the scope of this chapter. In weak solution, however, eserin has a powerful tonic effect on the ciliary muscle. In many cases of lack of tone in accommodation after illness or overwork the use of a solution of eserin (gr. 1/80-℥ss, one drop t. i. d.) will markedly increase the comfort of the eyes and restore the ability to work. Naturally, however, the ciliary muscle should not be compelled by any such means to a continuous compensation for refractive errors.

CHAPTER VI.

HYPEROPIA.

Hyperopia is the refractive condition of an eye in which parallel rays of light tend to come to a focus behind the retina and therefore form on the retina a diffusion circle of light instead of a point. Evidently the only rays which can come to an exact focus on the retina are those which were more or less convergent before entering, and since the emergent rays would take the same path, the rays emerging from a hyperopic eye are more or less divergent. Under these conditions, in a state of rest, the hyperope can form no distinct, sharp image of any object either far or near, but by using his accommodation enough he can see with the greatest distinctness at a distance, hence the hyperope is called "farsighted" by the laity.

Evidently there may be either or both of two conditions present as the cause of hyperopia: either the refracting media of the eye have less than normal action on rays of light so that the focal point is too far back, or the retinal screen may be too near the refracting surfaces. The first condition is spoken of as *refractive hyperopia* and may be due to a cornea which is flatter than normal, either from accident of birth or disease or to a diminished refractivity on the part of the lens. This tends to take place regularly with advancing years as the lens becomes less bulky and flatter in its curves. Extreme instances of refractive hyperopia occur in eyes in which the lens is wanting, as after a cataract operation or dislocation of the lens.

When the hyperopia is due to the shortness of the eyeball, it is called *axial hyperopia,* and this is much the commoner form. Most animals have axial hyperopia and that was probably the condition of human beings before the advance of civilization made the use of the eyes for near objects so much more important. Certainly the great majority of infants and young children are hyperopic, since before attaining full size their eyeballs are shorter in every diameter than later in life. As they reach maturity, the axial hyperopia tends to grow less and less as the eyeball increases in its antero-posterior diameter, while in old age, as we have seen, the hyperopia tends to increase again by the flattening of the lens, this time being of the refractive type. Of course, an eye in which the retina has been pushed forward by a tumor would be hyperopic, but generally speaking, hyperopia may be said to be a congenital difficulty which the great majority of individuals never entirely outgrow. Such eyes are optically imperfect, but are, as a rule, perfectly healthy in contradistinction to the myopic eye, which is almost always a more or less diseased eye.

The vision in hyperopia varies with the age of the individual and the amount of his error. Distant vision is possible only by exercise of more or less accommodation, but as long as this is active, the resulting vision is remarkably good. Being in constant use for distance as well as near vision, the ciliary muscle of the hyperope becomes regularly very much larger than in emmetropia, nor does it relax as completely. If we place before a hyperopic eye a convex glass which shall converge the rays of light so as to make accommodation unnecessary, the eye will see clearly till a glass is reached which converges the rays too much, when vision becomes indistinct.

The hyperopia indicated by the strength of the strongest glass which permits clear vision is spoken of as *manifest.* If, however, we place the eye under the influence of a cycloplegic, a much stronger glass will be accepted, showing that previously the patient had been unable to completely relax his accommodation. This extra hyperopia, which is revealed by a cycloplegic only, is the concealed or *latent* hyperopia, while the manifest and latent together form the *total* hyperopia. The manifest hyperopia varies greatly from day to day in some individuals, according to their ability to relax the ciliary muscle at the time. In very young people there is commonly a very slight ability to relax and therefore the manifest hyperopia is very small and the latent correspondingly large. Indeed it frequently happens that the contraction of the ciliary muscle is so great that the eye will accept no convex glass at all, in which case the entire amount is latent or concealed. With advancing years more and more of the error becomes manifest and less of it latent, so that in old age the hyperope will accept without a cycloplegic a glass which corrects his entire error. As long as he is able by the aid of accommodation to have distinct distant vision, his hyperopia is spoken of as *facultative,* while, when he cannot overcome his error by straining his accommodation, his distant vision falls below par and his hyperopia becomes *absolute.* Since the accommodation regularly fails with advancing years, even the slightest errors become in time absolute.

If the hyperope can see distinctly at a distance only by using his accommodation, he is at even a greater disadvantage when it comes to near vision. The emmetrope in doing work at a distance of ten inches is obliged to accommodate 4 D., but the hyperope who has to accommodate 2 D. to see distant objects like his rival, and then 4 D. more to read at ten inches, is evidently accommodating 6 D. If he has this amount at his disposal, he can see as distinctly as the other, but at the expense of greater muscular effort. There comes, too, a time when the accommodation of the emmetrope is no longer sufficient for his needs and he becomes the victim of presbyopia or old sight. Evidently the hyperope who regularly needs greater accommodative power, will feel this defect first and suffer from a premature presbyopia in proportion to the amount of his error.

The near point of the hyperope, then, begins to recede earlier than in emmetropia and finally even in the lower grades gets beyond infinity, after which distant vision also is below par.

There is another set of symptoms which often causes the hyperope far more trouble than mere indistinctness of vision. We have seen that by accommodating he can make both distant and near vision satisfactory for a long time, but accommodation is as distinctly a muscular effort as weight lifting. If the hyperope has a good ciliary muscle, leads a healthy outdoor life and seldom uses his eyes for close work, he may finally drift into a condition of absolute hyperopia without ever being conscious of fatigue, but if his error is high or his ciliary muscle a poor one, if he live a sedentary life and especially if he compels his eyes to do a great amount of continuous close work, as in school, he gradually develops a train of symptoms that eventually cause him great distress. First of all, perhaps, in the afternoon or evening after an unusually hard day's work, the accommodation suddenly becomes unequal to the strain, relaxes and, as he expresses it, "things get black before his eyes." After a few moments' rest he is able to go on with his accustomed clearness. Gradually these attacks begin to come earlier and earlier in the day, to last longer and come oftener, while the necessary periods of rest are longer and more frequent. Finally there is a kind of a haze due to poor focussing, over every near object he looks at. Associated with this is pain which may be slight, but is very often of the severest type; pain in the eyes, frontal headache, which often lasts for hours after the overwork has ceased and sometimes becomes so continuous and severe as to lead to the suspicion of organic disease. At the same time lesser troubles appear, such as watering of the eyes, inflammation of the lids, conjunctivitis of a mild grade, drowsiness on attempting to do any close work. Unless the cause of the discomfort is discovered it is laid to the light, ventilation, organic disease, nervous temperament, uric acid, malaria, or whichever of the terms for disguising ignorance is at the time popular. The patient drags out his more or less miserable existence till actual inability to see objects directs attention to the eyes, and when he gets his glasses, his symptoms magically disappear. In school children and young adults who cannot change their occupation, a habit of shirking tasks and giving inadequate attention is instinctively developed. Uncorrected refractive errors account for much inattention and apparent stupidity in children.

Hyperopia manifests itself frequently in the form of reflex disturbances in other parts of the body, such as indigestion with its allied evils, neuralgia, various neuroses, like neurasthenia, choreiform movements, cardiac palpitation and the like, and may be a contributing if not a primary cause of migraine and epilepsy.

It is particularly to be noted that very many of the patients afflicted with these symptoms, especially when young, retain their keenness of sight at a distance and can for a moment or two read the finest of print close at hand. The beginner should guard against the error of assuming that because a young patient has a vision of 20/20, he cannot have any refractive error. Indeed the presumption is in the other direction, since momentarily vision is a trifle sharper when the ciliary muscle is slightly contracted and a vision of 20/15 or 20/10 almost certainly indicates an accommodative effort which, if the patient were emmetropic, would reduce his vision materially.

As we shall discover in another chapter, there is a normal relationship between accommodation and convergence, and since the hyperope is constantly called on for an excess of the one, he very frequently also manifests an excess of the other, thus eventually developing either a latent or a fixed squint. Thus he has to make a choice of two evils. If he sees distinctly by accommodating, he immediately sees things double by over-convergence, while if he would avoid the diplopia, he must be content in many cases with less distinctness of vision. Sometimes he learns to accommodate without converging. Sometimes he is content with seeing poorly and occasionally he learns to converge his eyes as much as he pleases, while he avoids diplopia by suppressing one image. He therefore sees with one eye and squints with the other. Particularly is this the case when one eye is more hyperopic than the other, in which case vision both near and far is best in the eye with the lowest error, and consequently he fixes objects with this and turns the other in.

Diagnosis.—Hyperopia may be suspected from a history of the symptoms detailed above. In the old from the failure of distant vision which was once very clear; in the young from the history of gradually increasing difficulty from continued use of the eyes, blurring of vision, watering of the eyes and especially from pains in the eyes and headache, which are relieved completely or in part by rest, and aggravated by work. A positive diagnosis, however, can be made only from a careful objective examination which, withal, takes very much less time than the subjective tests. Especially to be relied on are the ophthalmoscope and the retinoscope, the uses of which in this condition have already been explained.

Treatment.—The treatment of hyperopia consists possibly of complete rest for the eyes, when they have become irritable and painful, and certainly in the prescription of convex glasses which shall correct all or part of the error. It is in the strength of the correction ordered that the judgment is called into play, since many competent men simply correct the manifest error, while others, fully as competent, advise correction of practically the whole amount. To me it seems that each case must be studied by itself and the correction graded according to the conditions present, and here again we must distinguish between the patient who comes because his vision is failing and the one who complains of headache or reflex trouble.

Patients of the first class are generally somewhat advanced in years, and if we order a glass which corrects the manifest hyperopia, the vision is brought up to normal and every wish is satisfied. If, however, we try to correct the total error of such a patient, we give him a glass stronger than he can readily use without a cycloplegic, and as regards vision, he is even worse off than before. After a time the patient's distant vision again falls below par, as his latent hyperopia becomes more and more manifest, and it is necessary to again correct it, till finally, in course of time, the entire error has been corrected. In younger persons who complain of tired eyes and mild headaches, I am accustomed to pursue the same course except that I am much more careful to reach the extreme limit of the manifest error. In cases in which there is headache of the severer and more continuous type, reflex symptoms, such as choreiform motions, tendency of the eyes to squint, and especially if there is reason to suspect spasm of the accommodation, I invariably use a cycloplegic. In young children, where one has to depend entirely on retinoscopy and ophthalmoscopy, a cycloplegic—preferably atropin—is necessary, because the accommodation is normally very active and beyond control and one can place no dependence on the subjective tests like the test cards and clock dials.

There is a certain routine procedure that each man must determine for himself, not only to save time, but to avoid forgetting details which ought to be recorded. For instance, a patient of 35 years comes complaining that in the afternoon his eyes get tired and water and feel as though they had sand in them and that he is unable to read at night because he gets drowsy or has a headache, while his vision for distance is very good. One suspects that such a patient is using his ciliary muscle too much and that it is becoming unequal to the strain, which would not be the case at this age, if he were emmetropic. We first test his distant vision at twenty feet on the trial cards, with each eye separately, and find V. 20/20 in each. Evidently he cannot be myopic, or his distant vision would be reduced. He may be emmetropic, but he may also have a hyperopia which he is compensating for by his accommodation, or he may be astigmatic. To experiment at this point with trial lenses is waste of time, because it would be done at random; so we at once take the patient to the dark room, place the light over his head and examine him with the retinoscope. We have him look clear across the dark room, being careful that there is nothing here which can particularly engage his attention and so stimulate his accommodation. In this way his ciliary muscle has a complete physiological relaxation. The surgeon places himself at a distance of about a metre in such a position that his right eye is just outside the visual line of the patient who is looking off into the distance. When the light is reflected into the patient's eye, the reflex is very clear and distinct, unless the pupil happens to be very small, and with practice this will become much less embarrassing. Retinoscopy with a small pupil is much easier if the room be absolutely dark and is almost impossible in a simple twilight. A "with the mirror" motion of the reflex, when the patient is not under atropin, invariably means hyperopia in that meridian. When we place before his eye a + 3 lens, the motion in all meridians stops, while with a + 3.50 it becomes "against" the mirror. It will be found that the strongest convex lens which just stops the motion, without deducting anything for distance, will represent very accurately the hyperopia.[1]

Right here it is interesting to have the patient look at the physician's forehead or his ear, as he might do if under a cycloplegic; in doing this he accommodates and appears much less hyperopic than he really is. The whole secret of successful retinoscopy without a cycloplegic is to secure a physiological relaxation of the ciliary muscle by gazing off into the distance. Having measured the right eye, the physician moves his seat or has the patient change the direction of his gaze, so that the physician's left eye is just outside the visual line of the patient's left eye. Let us suppose that the motion in this eye is brought to a stop by a

[1] If this patient were placed under atropin, a point of reversal at a meter would be developed with a + 4 D. and deducting 1 D. for distance, the result would be in the great majority of suitable cases almost the same as by the above empirical method.

+ 3 as in the other. We are sure that the patient has a hyperopia of at least 3 D. without any astigmatism.

Now we examine each eye with the ophthalmoscope, noting incidentally the pupillary reaction and whether the media are clear and the fundus normal. The strongest convex glass with which the finest retinal vessels can be seen is a + 3, which is therefore the measure of the hyperopia and corresponds with the retinoscopic tests.

With a reasonable amount of skill and experience the observer can judge from any discrepancy between the retinoscopic and ophthalmoscopic findings whether there has been a reasonably complete relaxation of accommodation during the first test. There is probably no accommodation, unless the image is first formed at the macula, and as the patient instinctively avoids focussing the bright light from the ophthalmoscope on his macula, there is usually a complete relaxation of the ciliary muscle during the ophthalmoscopic examination.

It is my custom next to examine the surface of the cornea with the ophthalmometer of Javal. This step is not absolutely necessary, but as explained in another chapter, most of the astigmatism met with is corneal and if the ophthalmometer shows that the cornea has no astigmatism or none exceeding a half dioptre, it simply furnishes a third indication that we have to deal with a simple hyperopia.

We now seat the patient before the test cards, and covering up the left eye, try to find the strongest convex lens with which he can retain his normal vision of 20/20. We are certain that if our patient were under atropin, he would accept a + 3 D. lens, but without the atropin we cannot expect so much. We first place a + 1 D. sph. in front of the eye and find that the 20/20 line is still distinct and immediately place over this a + 1.50, which reduces the vision several lines. When, however, we withdraw the 1 D. from the combination, the vision immediately becomes normal again. The idea in placing the second lens before the eye before withdrawing the first is to prevent the patient using his accommodation while the lenses are being changed. When we try the same maneuver with a + 1.75, he fails to read the line correctly and evidently + 1.50 is the manifest hyperopia in this eye.

We now cover the right eye and examine the left in exactly the same way, finding exactly the same result. All our tests have indicated that the eyes are exactly alike in their refraction and should have the same glass, but we find that by using both eyes together, a still further relaxation of the ciliary muscle takes place and that with a + 2 D. before each eye the binocular vision is still 20/20 and we prescribe this glass with the full confidence that it will relieve the symptoms complained of, and that without so diminishing the distant vision as to be disagreeable to the patient. It may be objected that the glass does not correct the entire error and that in near work it still leaves too much work on the accommodation, but it must be remembered that the hyperope has an unusually powerful ciliary muscle which, by the aid of the glass, is perfectly able to do this work. This patient can wear eyeglasses if he prefers them, the precaution being taken that the optical centres of the lenses come directly opposite the pupillary centres. He is instructed to wear his glasses constantly for near and far work till, after an interval of several weeks, his symptoms having abated, he is allowed to discard them on the street if he prefers, retaining them regularly for his near work.

The so-called "fogging" method which amounts to the same thing, consists in putting over the eye a convex lens strong enough to blur the distant vision badly, and then adding to it gradually increasing minus lenses till the patient's normal acuity is reached. This may be approximately estimated before hand by having him read through the pin hole disc which excludes from the eye all except the practically unrefracted axial rays.

Now let us consider another case, that of a boy of 12, who is brought because he is near-sighted, seeing badly on the street and holding his book close to his eyes in his efforts to read. On testing his distant vision, we find it 20/70 which inclines us to believe that the parental diagnosis may be right in spite of the rarity of myopia in children. Without wasting time in efforts to improve his vision at this time, we hurry him to the dark room, where the retinoscope shows a very faint reflex moving slowly but distinctly "with" the mirror. The defect is then not myopia, but a very high hyperopia, which we estimate as before by having the patient look into the distance while we find the lens which just stops the motion, a + 7 D. in this case. The ophthalmoscope shows the same amount in each eye, while the ophthalmometer shows no appreciable astigmatism. This patient has a hyperopia so high that one would expect at first sight all sorts of reflex pains and aches from which he has apparently been notably free. As a matter of fact, by straining his accommodation to the extreme, he has never had satisfactory distant vision and therefore he long ago ceased to try to see distinctly, while his case is still worse near at hand. Realizing unconsciously the futility of accommodating, he has acquired the habit of holding things close to his eyes so that his retinal images may be as large as possible, though indistinct.

When we place him before the trial cards, we find that a + 3 before each eye separately, gives him the maximum vision of 20/30, while with both eyes together he will accept a + 3.75. As far as his distant vision is concerned, this would be a very satisfactory glass, but it would leave almost too much ciliary strain in distinct near vision. It must be remembered that this is a school child who is backward and will have to do an unusual amount of near work, that even with this glass he would have to accommodate 3.25 dioptres more than his emmetropic neighbor, and while at his age his accommodative power is at its height, he has not used his accommodation like the ordinary hyperope, since it did no apparent good, and therefore his ciliary muscle is comparatively feeble. To prescribe this weak glass would improve his vision and stimulate him to force his eyes to work with which they are evidently not able to cope except for short intervals, and we should very shortly have the train of reflex headaches and symptoms from which he has hitherto been free. If we prescribe a + 5 for him, we reduce his distant vision to 20/50, but inasmuch as he has never in his life before seen better than 20/70, he will be encouraged to wear his glass constantly, while his vision will constantly improve as he gets used to the lenses till it again approximates the normal. At the same time we have placed his near vision well within his powers for years to come.

Now let us consider the case of a child of 4, who is brought because of a beginning squint. We can test his vision by marbles or other small objects and find it good in both eyes, but when we repair to the dark room, we cannot use the retinoscope because he insists on looking on the mirror instead of across the room. The ophthalmoscope shows a hyperopia of a 4 D., but we cannot say that there is no astigmatism. We might estimate his error from the ophthalmoscope alone and be approximately correct, but the only exact way is to put him under the influence of a cycloplegic and estimate his error by the retinoscope, which is comparatively easy as he is interested in the process and watches intently. Since his eye is under atropin we make the customary allowance for distance of one dioptre in using the retinoscope. By this means we find his error to be exactly 4 D. with no astigmatism. We prescribe nearly the full correction for its effect on the squint, though we are certain that as soon as he comes out of the influence of the atropin he will see somewhat better without his glasses. We can, by continuing the atropin a long time, get him to see well with his full correction, gradually discontinuing it as the glass is accepted.

Let us suppose the case of a school girl of 15, who comes complaining that she cannot see things on the street, while she constantly suffers from headaches, is getting nervous and irritable, and has to hold her book very close to her eyes in studying. A test shows her vision to be 20/100 in each eye. In the dark room the retinoscope shows a decided "against" the mirror motion of the reflex, which is stopped by a — 2 sphere. The ophthalmoscope shows the media to be clear and the fundus normal, the texture of the retina being visible at times with the aperture and again only with a — 1 or 2 D. lens. The ophthalmometer shows no astigmatism. When tested at the trial card, all convex glasses serve to make the vision worse, while with a — 2 lens the vision in either eye is brought up to 20/15. One who was not reasonably accurate in the use of his ophthalmoscope, would naturally conclude that he was dealing with a true myopia, but the fact that the fundus was visible if only for a second, with the aperture, showed that the eyes could not be actually myopic, while the fact that it was not always equally clear through the same lens showed a spastic condition of the ciliary muscle. There is nothing to be done with such a patient, but to examine again after several days' use of atropin. On the second examination the retinoscope, after making the correction for distance, shows a dioptre and a half of hyperopia which is confirmed by the ophthalmoscope. The patient's distant vision is now 20/40, which with a + 1.50 is brought up to 20/20 in each eye. She fails to accept any higher correction in both eyes together, since no further relaxation is possible over that produced by atropin. This patient has overworked her ciliary muscle till it refuses to relax when the stimulus of near work is withdrawn. Consequently she has pain from the cramped muscle, while her crystalline lens has for the time become so convex that the rays cross in front of the retina instead of behind it. To prescribe the concave glass, because it improves her distant vision, would simply impose additional work on her accommodation and would very shortly increase her reflex pains at the same time that it still further reduced her ability to see without the glass. The atropin ought to be continued in her case till we are certain the spasm is overcome which sometimes takes weeks, and to prevent its return she ought to wear practically her full atropin correction constantly.

The student will sometimes be in doubt, in cases where he has employed a cycloplegic and correctly estimated the total hyperopia, just what glass to prescribe. Some authorities prescribe practically the full correction in nearly all cases. The result is that in many cases the patient can, after emerging from his cycloplegia, see so much better without his glasses that he gradually discards them and perhaps entertains but a poor opinion of his oculist's skill.

One should hesitate about ordering a full correction unless there is some clear reason for giving it, which the patient is sufficiently intelligent to understand. Some men do not order glasses till the patient has come out of the atropin and been tested a second time, when they correct the manifest hyperopia only.

It is not to be forgotten that the amount of accommodation depends on two distinct factors: first, the elasticity of the lens and second, the actual muscular power of the ciliary muscle. The one fails regularly with age, but there is no reason for supposing that there is any material change in the other. The same muscular effort which at ten causes an accommodation of 15 D.; at fifty only causes 2, but by using his full muscular power, the patient may have very distinct distant vision without any evidence of overwork. If, now, we prescribe a glass which makes the muscular effort unnecessary, the muscle rapidly loses power and the patient soon becomes absolutely dependent on glasses for distant vision as well as near. This is to be avoided in many occupations, as in the railroad service, where inability to see without glasses is ground for discharge. In such cases it is policy to prevent overstrain by a full correction for near work and at the same time to compel the eye as long as possible to maintain distant vision without glasses. In the same way the failure of vision after exhausting illness is due, not to any change in the lens, but to sheer muscular inability to place it in a position of complete relaxation. In many cases it is better policy, by a judicious admixture of rest, exercise and tonics, to restore the function rather than to prescribe glasses which will prevent it by making the muscular effort unnecessary. This is best accomplished by forbidding near work entirely for a time, by general building up of the bodily health, by very weak eserin solutions, as ciliary tonics, and by under-correcting the distant vision or allowing no correction at all. In some cases it is even advisable to have the patient wear very weak minus spheres for a short period every day to compel exercise of his ciliary muscles.

As a rule we under-correct the total hyperopia, as estimated under atropin, by an amount which depends upon:—

1. The age of the patient. The younger he is and the stronger his ciliary muscle, the more we can safely leave for it to do.

2. The amount of manifest hyperopia. The less there is, the less of the total hyperopia we correct. As a rule we give a glass somewhat stronger than the manifest.

3. The symptoms. When the patient simply complains of eyes tiring and needing rest only after long use, we correct but little more than the manifest error; but when he is subject to marked asthenopia, headache, neurasthenia or other reflex symptoms probably due to his eye strain, we correct a much larger part of his error, and when there is developing an actual squint or spasm of the accommodation, we correct practically the whole error and, if necessary, insist on the patient's continuing his atropin till he can wear it comfortably.

4. The patient's requirements. If his employment is such that he has an unusual amount of near work, we correct more of his hyperopia.

CHAPTER VII.

MYOPIA.

Myopia is the term applied to the refraction of an eye in which parallel rays of light tend to come to a focus before reaching the retina. The only rays which can focus properly are those which enter divergent and must therefore come from an object at a lesser distance than infinity. Conversely, rays passing outward from the retina will emerge convergent. Evidently there are two factors which separately or together may produce this condition: either the refractive media of the eye are too strong, so that entering rays are made to focus sooner than normal, or the retinal screen may be placed back of the normal focus of the media. Myopia which is due to an excess of power in the refracting media is known as refractive myopia, while that due to faulty position of the retina consequent to an increase in the antero-posterior diameter of the eye is known as axial myopia.

Refractive myopia may be caused by a number of anomalies in the refracting media. For instance, an eye in which there is an abnormal convexity in the cornea with a consequent increase in its refraction would tend to be myopic, and, as we shall see, the convexity of the cornea as indicated by its radius of curvature is a very important factor in aiding us to decide whether a myopia is likely to be stationary or progressive.

Any bulging of the cornea as the result of disease like a staphyloma would tend to make the eye myopic. Another important factor in refractive myopia is the lens. If the lens is abnormally convex or is of unusual density, its refracting power is increased, so that rays of light are brought to a focus before reaching the retina. This is very commonly noted in the early stages of cataract in which the lens swells, without as yet losing its transparency. In this condition the emmetropic patient becomes very myopic, is able again to read fine print without glasses and is said to have attained his "second sight," while the hyperope again sees distinctly at a distance without glasses and substitutes a weaker pair for his near work. This occurs so regularly that a boast of second sight should always make us suspicious of incipient cataract. A dislocation of the lens so that it occupies a position nearer than normal to the cornea would tend to cause a myopia, especially marked, because with the tension of the zonula removed, the lens would become very convex. A much commoner form of refractive myopia is due to *spasm of the ciliary muscle,* by aid of which the lens becomes abnormally convex, and which persists as long as the spasm lasts. This is often due to faulty ocular hygiene, in holding print within a few inches of the eyes and then focussing on it, as many children do when they lie on the floor or sit with elbows on the desk. When they look up the ciliary muscle fails to relax and the eye remains apparently myopic. This may finally result in a real axial myopia.

Axial myopia is due to an elongation of the posterior segment of the eye, with a consequent backward displacement of the retina. An eye with refractive myopia may generally be considered as an eye which is optically imperfect, but perfectly healthy, while an eye with axial myopia is always a diseased eye, with potential dangers so great that special attention should be paid to its cause and the steps in its development.

Myopia is only in the rarest instances congenital, since we have already seen that the great majority of children are born hyperopic. It only exceptionally occurs among savages or those who lead an outdoor life, while amongst civilized people it seems to be prevalent in exact proportion to the amount of close work done. Among school children it is rare in the primary grades and increasingly common as the higher strain of education increases, so that in the high schools and colleges it is very prevalent. A study of different occupations shows the same thing. Almost unknown among farmers and outdoor workers, it is very common in factory workers, type setters and others who are obliged to do close work continuously, each decade showing a larger and larger percentage of cases. It is notably more common among people who have wide foreheads and eyes set far apart, and if any race has predisposition to it, it is the races of the German or Slav types, in which this form of skull predominates. While not congenital, the tendency to the disease is without any doubt hereditary, since it very commonly occurs generation after generation in the majority of members in certain families in which the children, though born hyperopic, sooner or later become myopic. Few diseases have been more carefully studied than axial myopia, and while the results are still in many respects indefinite, we have a working hypothesis of its development based on statistical information.

In the broad-skulled individual of the German type it is evident that since the eyes are set wide apart, they must converge much more than normal in doing the ordinary school or factory work at distances of ten or twelve inches. Consequently the eyes are subject to undue pressure from the extreme tension of the recti muscles. This alone should tend to elongate the eye, but as we shall have occasion to notice repeatedly, there is a normal relationship between convergence and accommodation, so that the patient who has to converge too much, also accommodates too much.

This takes place in our patient. When he converges his eyes on an object twelve inches away, the extra effort made necessary by the abnormal distance between his eyes is immediately responded to by an extra tension of the ciliary muscle, and his eyes, instead of being accommodated to an object at twelve inches, see it much better when it is brought up to ten. But when the object is brought up to ten inches, more convergence is necessary to keep both eyes on the same object. Thus is instituted a vicious circle, each effort at clear vision calling for an increase in convergence, while each increase in convergence is automatically associated with an increase in accommodation which again calls for more convergence. This constant contraction of the ciliary muscle not only tends to drag the walls of the eye toward the axis, but also by slightly compressing the contents to force the cornea and fundus further apart, and so of itself creates an axial myopia out of that which has so far been refractive. As the axial myopia develops, the patient's ability to see things close to either eye gets entirely beyond his power of convergence, and he gives up unconsciously all attempts at binocular vision and learns to suppress one image; and as he is now so myopic that he can see without accommodating and is no longer bothered by diplopia, he ceases to converge. As we shall see in another chapter, the overworked muscles rapidly lose power, and very commonly a divergence of the eyes follows.

But every pair of eyes in which there is an excess of convergence and accommodation does not develop an axial myopia, otherwise nearly every hyperope would eventually become a myope, which is very far from being the case. Evidently something further is necessary. The conditions referred to doubtless cause the tendency to elongation of the eyeball, but the elongation does not take place unless the tissues in the posterior half of the eye are softened by disease and so more susceptible to the stretching process. This tendency to scleritis and chorioditis, which is so common in myopia, may be part of the individual heritage or it may be in part the result of the chronic congestion resulting from the constant strain of the eye. At times it occurs at the equator of the eye in the form of a scleritis, and the elongation of the eye is due to a stretching here, but in the great majority of cases the change takes place about the posterior pole of the eye which keeps bulging further and further back into the orbit, the bulge constituting what is known as a posterior staphyloma or sometimes as a myopic staphyloma.

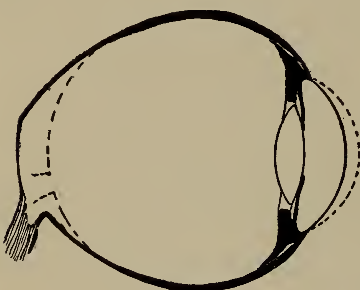


Fig. 65.

There are a number of anatomical changes characteristic of myopia. The antero-posterior diameter is so much increased that very frequently the eye seems to project forward from the orbit and be with difficulty covered by the lids, constituting what is commonly termed a "pop" eye. The pupil is very large and the patient commonly has a habit of squeezing his lids nearly together to exclude some superfluous light and make his vision better, by cutting out the diffusion circles in the same way that a pinhole disc would do. The anterior chamber is very deep and in well-developed myopia each eye singly sees so much better, both near and far, with the ciliary muscle completely relaxed, that finally from sheer lack of use it becomes much smaller than normal. But the most marked changes are those which can be seen at the fundus with the ophthalmoscope. Very early there develops at the posterior pole and about the macula a condition of chronic congestion of the chorioid and retina which, instead of the clear, transparent red, shows a mixture of red and yellow and brown, which has been very aptly compared to the color of a ripe peach, and as the condition persists, more and more pigment is deposited, till finally we have the picture of a chorioiditis without exudation.

Very early changes take place in the nerve head which, it will be remembered, enters somewhat to the nasal side of the posterior pole, and in the normal eye is practically perpendicular to the sclera at its point of entry. In the myope, as the stretching process proceeds, the posterior pole is pushed further and further backward till the nerve appears to enter nearly at right angles to its normal course, while at the same time the abnormal convergence in front causes an abnormal traction on the nerve behind. The nerve head instead of being in the same plane as the retina is pulled into a funnel shape, which points toward the outer side of the eye, having its inner side perpendicular to the observer and indistinct, while its outer side is very conspicuous. The blood vessels often have a sharp bend and appear to come from the inner side of the nerve instead of from the centre. Chorioidal changes begin at the outer side of the nerve head, first in the form of a yellowish-red border which finally results in a local atrophy of the chorioid, allowing the glistening white sclera to show through. This constitutes the so-called *myopic crescent,* or conus, which, to the beginner, appears as part of the nerve head, but is to be distinguished because it is generally much whiter and very often has a border of brilliant black pigment. This crescent, beginning at the temporal side, sometimes extends all around the nerve head and broadens till the entire region is filled with an area of glistening white. This is sometimes erroneously called a staphyloma, which is, however, a very different affair. The true staphyloma generally occurs considerably to the temporal side of the disc, where a whole section of the sclera, thinner and softer than normal, gives way and forms a saucer-like depression, sometimes a third of the whole fundus being involved, and which is visible, not because of any changes in color, but by the change in the course of the vessels as they dip down into it.

Under such conditions none of the tissues of the eye are properly nourished; the retina partakes of the changes which take place in the chorioid and loses more or less of its delicacy of perception, while, as it is no longer held against the latter by the shrunken vitreous, it is especially liable to detachment, which is the final stage of many high myopias. Changes in the circulation make the myopic eye very liable to retinal and chorioidal hemorrhages, which are especially likely to occur about the macula. Floating opacities in the vitreous are very common sources of complaint.

Symptoms.—The symptoms in myopia depend on the amount of error present, and whether we have to deal with the benign refractive type or the progressive axial form. The *distant vision* is always reduced in direct ratio to the amount of myopia. The myope of 2 D., without using his accommodation, can focus on his retina rays from an object twenty inches away and get a distinct image, but the rays from an object farther away than this come to a focus more or less in front of his retina and so form on it diffusion circles which always results in indistinct vision. This point, which is also the point where emergent rays cross, is the myopic far point. Objects within his far point he can see by accommodating and if his ciliary muscle is normally strong, he is evidently able to bring objects

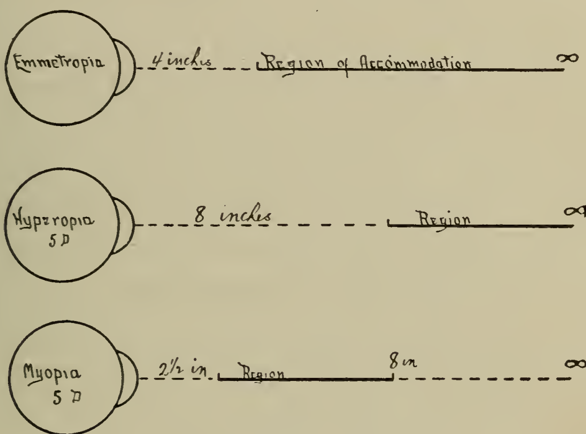


FIG. 66.

much closer to his eye and preserve distinct vision than the emmetrope. The closest point at which distinct vision is possible is the near point, and the distance between the far point and the near is his region of accommodation which differs materially from that of either emmetrope or hyperope, as shown in the diagram. Let us suppose the individual to be 20 years old, in which case he should have a ciliary power equal to about ten dioptres.

The emmetrope, with his accommodation relaxed, has his eye adapted to parallel rays coming from infinity, while by exerting his ten dioptres of accommodative power, he can focus rays from a point four inches in front of his eye. His region of accommodation reaches from four inches to infinity. If he had 5 D. of hyperopia he could not focus parallel rays except by accommodating 5 D. and the remaining 5 D. would enable him to focus rays from an object at eight inches, but no nearer. Evidently his region reaches from eight inches to infinity. If he were myopic 5 D., he could not see clearly *beyond* eight inches, even with his accommodation completely relaxed, and if we add to the 5 D., which he has by reason of his myopia, the 10 D. of actual accommodative power, his near point is that of an emmetrope of 15 D., or practically 2½ inches. In other words, his region of accommodation reaches only from 2½ to 8 inches; but he has one advantage over the other two in that, though his distant vision is very poor, he can see close at hand with a much smaller expenditure of muscular energy. We have seen that at forty years of age the average person has a range, or amplitude, or power of accommodation, of about 4.5 D. which brings his near point up to about nine inches if he is emmetropic. If he is hyperopic 2 D., his reserve of accommodation is only 2.5 D., which leaves his near point at about sixteen inches and has long since driven him to wear reading glasses. The myope of 2 D. at forty has his near point at about six inches and it has not receded to nine inches till he is about fifty years of age, while in the higher grades of myopia he might never have to wear a convex glass for close work. In other words, his presbyopia is delayed, or, perhaps, does not occur at all.

While it may be truly said that in the lower degrees of myopia the indistinctness of distant vision is largely compensated for by the ease of close work, and the postponement of presbyopia, the case is very different when the degree is higher and tends to become progressive. In many such cases distant vision is reduced to mere perception of form and motion, and the individual is doomed to a lifetime of peering and blinking. Meantime the far point is so close to his eye that binocular vision is possible in reading only by the greatest effort. In the higher degrees, too, it often happens that improvement by glasses is not satisfactory, since the nutrition of the retina has suffered so by the changes in the fundus that it has lost a large part of its delicacy of perception. The myope is subject to constant annoyance from muscæ volitantes, or floating specks, which are particularly noticeable when the eye is tired and the gaze is directed toward a white surface. Not infrequently the patient is conscious of the larger floating bodies in the vitreous which can be seen with the ophthalmoscope, and has blind spots of greater or less extent from chorioidal atrophy or hemorrhage or retinal detachment.

Pain in the eyes, headache, and a whole train of reflex disorders which so often pursue the hyperope, are comparatively rare in *pure* myopia, since no effort of his accommodation is of any use for distant vision or of any necessity for near. In many of the cases the extreme convergence necessary for binocular vision causes pain, but after a time, most myopes reach a working basis by abandoning binocular vision even though the eyes do not actually diverge. The chief source of pain in many cases is this: that the myope, like other persons, sees things close at hand more sharply when his ciliary muscle is under some tension, and consequently the tendency is to hold objects a little closer than is absolutely necessary and so throw work on the ciliary muscle which it is not capable of performing without effort. In such cases the muscle may respond to the demands and increase in strength, thus relieving the pain; it may break down entirely under the strain, in which case the pains are greater and more continuous, till use of the eyes becomes impossible; or it may get into a state of irritability and develop that spasm which plays such a part in the increase of myopia.

Prognosis.—It is very important to be able early in life to form an intelligent estimate as to whether the myopia in a given case is real and, if so, whether it is benign and stationary or pernicious and progressive. In the first case there is no occasion for anxiety, but in the second, the whole trend of the child's career is changed, since every possible strain on his eyes must be avoided. His education must be limited both in amount and in kind and he will afterward be debarred from any occupation which involves continuous use of the eyes.

In the first place: Is the myopia a real one? We have seen that children are born hyperopic, that they become myopic gradually, and that in a hyperopic child a spasm of accommodation may at first simulate the myopia which it afterward frequently produces. A correction in such a case without a cycloplegic only increases the difficulty and no mild cycloplegic will be of avail. Let it be atropin and let it be used several days to be sure of complete relaxation. A careful study of the hereditary tendencies of the child, the width between the eyes, the amount of convergence necessary for near work, as well as of the medical history, should be made, since they all show a tendency one way or the other; but the two most important points are the measurement of the radius of curvature of the cornea and the examination of the fundus. It will be remembered that the average cornea has a radius of curvature of 7.65 millimetres. If the radius of curvature is less than this, it indicates a cornea with a sharper curve and greater refracting power, while, if the radius be longer, the cornea is flat and under-refracts. This radius can in each case be measured with great accuracy by the ophthalmometer of Javal, as explained in another chapter. A short radius in myopia indicates that the case is of the benign refractive type in which the rays are prematurely brought to a focus by over-refraction. A long or even an average radius, on the other hand, indicates that any myopia present must be due to the displacement of the retinal wall backward, which would indicate the progressive axial type. Examination of the fundus is also of great value. If no changes are present in a patient with a short corneal radius it is perfectly safe to say that the case is a non-progressive one. If the cornea is a flat one, the absence of fundus changes is not so conclusive, since the myopia is evidently axial and not refractive, and the changes are likely to develop later; while, if the changes are present which indicate an inflammatory softening of the structures at the posterior pole, the diagnosis of a progressive myopia can be made very positively. Without corneal measure of this kind the value of statistics of the results of various methods of treating myopia have a very problematical value, since we are in no position to even guess what proportion of the cases would have remained stationary without any treatment.

Treatment.—Prevention is better than cure. We have seen that in predisposed individuals an over-use of the accommodation finally resulting in spasm is one of the early factors in the disease. This occurs not only in myopia itself, but in low degrees of hyperopia and especially of hyperopic astigmatism, and any indication of over-stimulation of the ciliary muscle of a child should be met by a careful correction of the refraction and, if necessary, a temporary relief from school duties. The same rules obtain with young factory workers, who should restrict the use of their eyes for close work as far as possible.

When we place a concave glass of suitable strength before the myopic eye, the rays of light which, entering parallel, focus in front of the retina are made just divergent enough to fall on the macula. If we place a somewhat stronger glass before the eye, the rays are made so divergent that they tend to focus behind the retina, but the patient applies his accommodation to these divergent rays and makes them focus, till a glass has been reached which is beyond his power to overcome. Just as the distant vision of the hyperope is better with a glass which only partly corrects his error and allows him to accommodate, so the myope sees very much better with a glass which overcorrects his error and so enables him to use his accommodation. At first sight it might seem that this would do no harm, as long as it gives such good vision, but if we remember that the ciliary muscle is small in myopia, the keenness of distant vision would be preserved at the expense of fatigue, while the additional strain of near vision would often prove entirely beyond the individual's power, even if his myopia were of the benign type.

Long series of cases have been presented to show that the complete correction of the entire error of refraction in myopia prevents its progression in the great majority of cases, and the tendency among leading ophthalmologists is to follow this rule. But we know that only a minority of myopes, after all, have the pernicious type, and till we have the records of a large number of patients in whom myopia was proven to be axial, together with the data of the age, hereditary tendencies, etc., we are not in a position to more than guess at the proportion of cases which have been rendered non-progressive by full correction. Meantime there are some advantages about under-correction as well as exact correction in certain cases, and while a definite rule saves much thought and many mistakes to the beginner, the more experienced man is only embarrassed by it. One ought always to be conscious of the likelihood of over-correcting every case in which a cycloplegic has not been used, and while this in many cases has been proven harmless, in many more it is a grave error, especially as the myope does not ordinarily make much use of his ciliary muscle and is therefore but slightly incommoded by a cycloplegic.

Estimation of Myopia.—We approximately estimate his visual capacity by having him read without glasses through the pin hole disc which excludes from the eye all but the unrefracted axial rays, while if he can read No. I J. type without glasses when held sufficiently close to the eye his macula must be functionally useful. After this preliminary test we take the patient to the dark room, and if not under a cycloplegic, we get him to relax his ciliary muscle by gazing off into the distance while we use the *retinoscope.* The weakest concave glass that stops the motion of the reflex is approximately the measure of the myopia. No pretense is made that this method is either absolutely reliable or accurate, but it is a convenient way of rapidly getting at a patient's condition, since it estimates the error with great rapidity and sufficient accuracy and saves time spent in experimenting at the trial case. By using the retinoscope, while the patient wears his own glasses, one can tell at once whether there has been any material under- or over-correction. In elderly people, whose accommodation is no longer active, it is a very satisfactory method of making a final estimate of the refraction, while in the very high myopias it is, for reasons which we shall presently see, a very much more reliable method of measure than that with the ophthalmoscope, since the lenses are always placed at the same distance in front of the eye. Retinoscopy without a cycloplegic is easier in myopia, because of the large pupil usually present.

The Ophthalmoscopic Examination.—First, using a convex glass, we examine the media for opacities, try the pupillary reaction and then approaching very close to the eye we examine the fundus with the weakest concave glass with which we can see the tapetum of the retina or the small vessels in the neighborhood of the macula, this glass being the measure of the myopia. By using a stronger glass, one can see equally well, but it is done by using the accommodation and hence it is not the true measure of the refraction. We now examine the fundus carefully for any evidences of lesions, such as a crescent about the disc, chorioidal changes at the macula, a beginning staphyloma, retinal hemorrhages or detachment, making a careful note not only of their presence, but also of their extent, so that we can judge intelligently later on whether the condition has progressed or improved. In the high degrees of myopia the direct examination of the fundus is often difficult and one can get a much better general idea by the indirect method, which, because of the large pupil, is easier than in hyperopia. The magnification is, however, so much less that one is apt to overlook small but important details.

In the lower degrees of myopia up to eight or ten dioptres, the measurement of the refraction with the ophthalmoscope is likely to be fairly accurate, but in the high degrees of twenty dioptres and more there is a great likelihood of error. For instance, a myopic eye of twenty dioptres has a far point of only two inches and would be corrected by a concave glass of 20 D. placed in contact with the cornea, but the concave glass loses strength by being placed further away and has to be made correspondingly stronger. At a distance of 13 mm., or half an inch, which is the usual distance of spectacles from the cornea, it requires a glass of 30 D. strength to produce the same effect. If the glass is placed at a distance of 20 mm., or practically ⅞ of an inch away, the correction becomes 35 D. In using the ophthalmoscope, uniformity of distance is hardly possible, owing to the shape of the forehead of both patient and physician, and unconscious errors are unavoidable. The closer the observer brings his eye to that of the patient, the less the likelihood of serious over-estimate.

We now examine the eyes with the *ophthalmometer* of Javal, which gives us the radius of curvature and indicates the presence or absence of corneal astigmatism, at the same time giving very strong evidence as to the myopia being refractive or axial.

We next examine the patient's vision at the *trial case,* always remembering that a patient with normal vision cannot be myopic. After making a note of the vision in the right eye, we place before it a glass somewhat weaker than the one we expect the patient to use and gradually increase its strength till we find the weakest glass which will secure the maximum vision. Not being under atropin, the patient will use his accommodation and invariably prefer and see better with an over-correction of the error. When we have gone through the same process with the other eye, we let the patient use both eyes together, thereby relaxing the accommodation, and try to secure the same vision with a weaker glass before each.

Treatment.—If the patient has come simply because his distant vision is defective and complaining of no headache or reflex disturbances, if his error is not high, while the retinoscope, ophthalmoscope and trial case show the same amount of myopia without astigmatism, and if the myopia is refractive and not axial, we can safely prescribe at this visit. On the other hand, if the patient has reflex trouble of any sort, a high error, with changes in the fundus, if there is any discrepancy between the different tests, if the vision with glasses is unduly reduced, and especially if there are any indications of a progressive, axial myopia, the patient should be put under atropin and examined again.

The strength of the glass ordered is a matter of individual judgment, and it is to be remembered that we are now dealing with simple myopia, which is a very different thing from myopic astigmatism. If the patient has a myopia of 1 D., he needs his full correction for distance, while for near work he can use his glass or not as suits him best. If his distance correction is 5 D., he will be obliged, without glasses, to bring fine print up to eight inches which is too close, while the use of his full correction for near work puts a strain on his hitherto unused ciliary muscle. If he is young and strong, he soon develops a normal power and can wear his glass constantly without trouble; but if older he must have the glass for near work reduced should he develop symptoms of overstrain. The same reasoning applies to the higher grades. They all need their full correction for distance and in many cases are not injured by slight over-correction, while very commonly they are much more comfortable with a reduction for near work.

If the myopia tends to be progressive, near work should be reduced as much as possible and in many cases interdicted altogether.

Another very important point is that the myope almost always holds things closer to his eyes than is really necessary, and so puts an undue strain on both his accommodation and his convergence, and he should be made to practice complete relaxation by increasing his working distance to the extreme limit.

In high myopias, with opacities in the media and changes in the fundus, the very great improvement both subjective and objective that follows the use of the iodides in the form of the ordinary mixed treatment, should be borne in mind.

Another procedure that has been much more thoroughly tested in Europe than here, is the reduction of the myopia by the formation of a traumatic cataract by discission, with the subsequent removal of the lens after the method of Fukala. The advantages of the procedure are that in suitable cases it makes a complete abolition of the accommodation by removing the lens, and lessens almost to nothing the convergence by removing the far point. It would seem hardly justifiable in eyes whose vision with glasses is good, and unduly dangerous in eyes already subject to chronic chorioidal changes. The ideal case would seem to be the high myopia without serious fundus changes, but with indication of progression.

The amount of reduction in the myopia by extraction of the lens is rather a complex problem. We know that in the emmetropic eye removal of the lens causes a hyperopia of about 11.5 D., which at the usual spectacle distance is compensated for by a + 10 D. lens. In myopia, if the lens was at a normal distance from the retina (the myopia being corneal), its removal would reduce the myopia 11.5 D. actually, which would be equivalent to about 13.5 D. estimated at the spectacle distance. Such a patient would after operation have a practical emmetropia for distance. If, however, as in most myopic eyes, the distance between the lens and the retina is greater than normal, the removal of the lens would have a proportionately greater effect. As it is not possible to measure accurately these distances, the effect of the operation is rather uncertain, reducing the myopia between a minimum of about 15 D. and a maximum of 25 D. Therefore, if the myopia be less than 15 D., the operation is not advisable, since the patient would have to wear a convex glass for distance and another stronger one for near work, and his eye would be deprived of the adjustability for different distances which goes with accommodation.

In prescribing glasses of all kinds, the physician should convince himself that the optical centre of the lens, as found on page 30, should be exactly in front of the centre of the pupil to avoid the prismatic action of the lens on rays which pass outside. This is much more important in myopia, since the average error is much higher than in other conditions. A patient wearing a — 10 D. lens, improperly centred, has to overcome a very powerful prism whose strength increases progressively from its centre.

CHAPTER VIII.

ASTIGMATISM.

Astigmatism is the refractive condition of an eye in which rays of light do not come to a focus at any single point, owing to irregularities in the curvature or density of the refracting media. It is by far the most important and difficult refractive error with which we have to deal, because the majority of patients have it in greater or less degree and because, even when so slight as to cause no perceptible diminution in distant vision, it commonly entails a multifarious set of direct symptoms grouped under the term "eye strain" or asthenopia, and is secondarily the cause of a host of reflex functional troubles ranging from headache to the most intense mental depression. It is certainly capable of eventually causing organic changes in the eye, and many authorities are arguing that it may also result in organic disease in other organs. It is the most difficult subject in refraction. Astigmatism is of two kinds, regular and irregular.

Irregular Astigmatism occurs when the curvature or refracting power in any one single meridian is not everywhere alike, so that rays passing through it never focus at the same point. This is most marked in diseased conditions of the cornea. For instance, if the centre of the cornea is flattened or pushed forward, it has an entirely different refractive power from the periphery, and rays of light which pass through are broken up as they would be by a flaw in a window pane. When the cornea is studded with numerous facets as the result of the contraction of ulcers in cicatrizing, the irregular astigmatism is still more marked, while after severe types of keratitis light may be as much diffused as is the sunlight in passing through a ground glass, in which every facet acts as an independent optical system.

Some irregular astigmatism is present in the lens of every eye. The lens, it is to be remembered, is made up of several sectors reaching from the equator to the centre, each one of which differs slightly in curvature and refraction from its neighbor. For this reason rays from a point of light at infinite distance, like a star, are refracted unequally by the different sectors, though the variation is so slight that the images generally overlap and give the impression of a star instead of a mere point of light. If the refractive power or curvature of these sectors is abnormally increased by disease, one or more of the points of the star become absolutely distinct from the rest as a point of light, and monocular diplopia develops, or polyopia. This very often occurs in incipient cataract, when the sectors of the lens are unequally swollen, but are yet transparent.

Irregular astigmatism reduces the vision and causes distortion of objects, which it is beyond our power to correct by glasses. Sometimes vision is very much improved by placing before the eye an opaque disc with a pin point aperture, in this way reducing the illumination, but also shutting out many rays which, by irregular refraction, would cause confusion. This is especially useful in keratitis, after trachoma, or in corneal ulcers, where one or more small areas of healthy cornea are left.

Irregular astigmatism, as the result of corneal scars or lenticular opacities, can be readily diagnosticated with the ophthalmoscope, using a strong convex lens and gradually approaching the eye, when the opacities appear black against the eye reflex. Transparent irregularities are best seen with the plane mirror in retinoscopy, when they appear as ill-defined, wavy lines or masses against the red background, while the reflex seems to consist of several portions, some of which move with the mirror and some against it.

Regular Astigmatism occurs when the refraction throughout any single meridian is the same. Such astigmatism is generally corneal and occurs when the curvature of the cornea is greater in one meridian than in another. As a rule the meridians of greatest and least curvature are at right angles to each other and are called the principal meridians. Such a cornea has a surface like the side of an egg or the bowl of a spoon, and it will be useful to study the path of rays of light after passing through such a medium. If we think of the spoon as standing vertically on its point, its sharpest curve will be in the horizontal meridian and the slightest in the vertical, these being the principal meridians, while the other meridians will represent curvatures gradually decreasing from the sharpest to the slightest. If we place a cylinder with its axis vertical, we find that rays of light passing through it are bent toward the axis and come to a focus in a vertical line, called the focal line, and if we place another cylinder before the first one with the axis horizontal, the rays also are bent toward the focal line which is horizontal. If the cylinders are of the same strength, the focal lines must be at the same distance away, and evidently all the rays focus at the point where the focal lines cross each other, and the combined cylinders are equivalent to a spherical lens. If the horizontal cylinder is weaker, its focal line will be further away, but the rays still pass through both focal lines, but evidently have no common focal point, since the lines do not intersect. The effect will be exactly the same, if the two cylinders be combined in a single lens having a greater curvature in one meridian than in the other. Such a surface is called a toric surface and corresponds to that of the cornea in regular astigmatism.

Rays from an infinite point of light will be refracted by the vertical cylinder so as to pass through the vertical

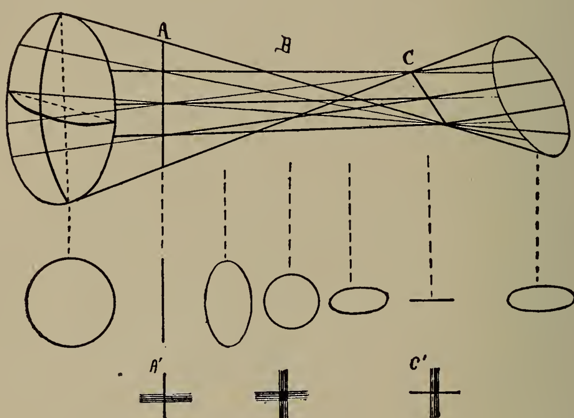


FIG. 67.

line *A*, and by the horizontal so as to pass through the horizontal line *C*, while if a screen be placed at various points in the path, the image formed will be a circle, a vertical line, a vertical ellipse, a circle, a horizontal ellipse and a horizontal line.

When the image of a point is a circle, it is known as the circle of least confusion.

This accounts for the peculiar vision of the astigmatic, in whose eye the cornea is a toric surface and the retina the screen, the image formed evidently depending on the difference in the refraction of the two meridians and the distance of the screen.

The image of a point, if the retina be situated at *A* would be a vertical line, at *B* a diffusion circle, and at *C* a horizontal line. If the object of regard be a vertical line, made up of an infinite number of points, each point will appear at *A* as a line, and as they overlap each other, the result will be a black, distinct vertical line; at *C* on the other hand each point will appear as a horizontal line and the composite result will be a broad indistinct vertical line composed of an infinite number of horizontal lines superimposed. A horizontal line is most distinct at *C*, and least so at *A*. If the object of regard be a + , it will appear at *A′* as  and at *C′* as , while at intermediate points neither arm is distinct. If the cross is not vertically placed, the lines are nowhere distinct without tilting the head, which is a fact to be remembered in studying the effects of astigmatism. The astigmatic patient, therefore, sees some letters much better than others according as the lines of which they are made up accord with the axis of his astigmatism, and we always have reason to suspect this error when the patient regularly miscalls certain letters in the test chart, while apparently reading without difficulty others of a very much smaller size.

While regular astigmatism in the great majority of of cases is due to the cornea having a greater curvature in one meridian than in the others, it is evident that the same effect would be produced by inequalities in the curvature or position of the lens. Regular lenticular astigmatism is generally attributed to an excentric or oblique position of the lens which is rotated slightly on its vertical axis, thus increasing the refraction of rays which enter in the horizontal meridian. According to Tscherning the lenticular astigmatism is slight, varying from .25 D. to .75 D., and as we have no clinical means of measuring it by itself, it is commonly disregarded. A very high degree of obliquity of the lens, like that caused by a partial dislocation, might produce a corresponding astigmatism.

Causes.—Regular corneal astigmatism is due in many cases to asymmetrical development of the eyeball. The orbit is narrower in the vertical diameter than in the horizontal, and the eyeball in conformity is slightly flattened above and below. It seems natural that the anterior corneal segment should have a slightly sharper curve in the vertical than in the horizontal meridian and this we find in the great majority of eyes. In some cases, however, the horizontal curve is the sharper, and an effort has been made to prove that all astigmatism in excess of the physiological type alluded to above, is the result of defective cranial development. Another factor that must not be lost sight of is the effect of the continuous pressure of the upper lid, which would tend to increase the vertical curve. This is especially noticeable in myopes and others who habitually screw their lids together to avoid light and secure better sight, and the tendency would be increased by inflammatory conditions which both increase the weight of the lids and the photophobia. A tendency to a sharp curve in the horizontal meridian follows the over-use of the straight muscles of the eye, especially the internus in converging. One has frequent occasion to notice in using the ophthalmometer that the astigmatism sometimes varies a couple of dioptres, owing to the lid and muscle pressure in a nervous child, while there are many instances on record of change in the corneal curve as the result of the lowered pressure after a tenotomy for squint. Very high degrees of corneal astigmatism often result from operations on the eyeball. For instance, after an upward section of the cornea for cataract, the lips of the wound regularly heal in an overlap, causing a marked flattening of the vertical meridian with a relative increase in the horizontal curve. Most of this astigmatism disappears after the lapse of several months.

VARIETIES OF ASTIGMATISM.—Since the vertical meridian has the sharpest curve in the great majority of cases, the variety is spoken of as astigmatism "with the rule," while the variety in which the horizontal curve is sharpest,

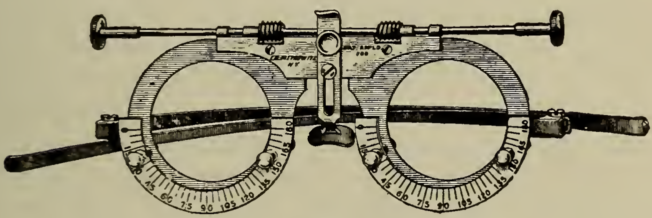


FIG. 68.

being the exception, is spoken of as "against the rule." Both are unfortunate and confusing terms, but seem to be firmly engrafted into our terminology. It is the custom to consider cases in which the meridian of sharpest curvature is nearer the vertical or nearer the horizontal, as being with the rule or against the rule, respectively. A much better way is to classify the astigmatism according to the axis of the meridian of greatest curvature. The ordinary trial frame in use has degrees marked on the circumference of each cell for this very purpose, beginning with 0 on the right side of each, as shown in Fig. 68. Thus in both eyes the vertical meridian is at 90°, and the horizontal at 180°. In the majority of cases the meridian of greatest curvature corresponds in the two eyes. If it lies at 90° in one, it is very apt to be the same in the other. If it is inclined toward the nose in one, it is apt to be so in the other and be recorded at 75° in the right and 105° in the left. Very often both meridians are inclined to the temporal side, the angle of inclination being equal in each.

Astigmatism is also classified according to the refraction of the different meridians. For instance, in an eye in which one meridian is emmetropic and the other hyperopic, the astigmatism is spoken of as *simple hyperopic.* If both meridians are hyperopic, but more so in one than the other, the astigmatism is *compound hyperopic.* If one meridian is emmetropic and the other myopic, the astigmatism is *simple myopic,* while, if both are myopic, but one more than the other, the astigmatism is *compound myopic.* *Mixed astigmatism* is present, when one meridian is myopic and the other hyperopic. In all these cases the amount of astigmatism simply measures the difference in curvature of different meridians. In any of these we can make the horizontal curve equal by adding a convex cylinder with its axis vertical (90°) or by subtracting from the vertical curve by a concave cylinder axis 180°, whichever gives the best vision. Therefore, convex cylinders at the axis 90°, or concave at axis 180°, indicate an astigmatism with the rule. Many writers consider that cases in which the axis of the correcting glass is within 45 degrees of the vertical and horizontal, should be included, as shown in the diagram.

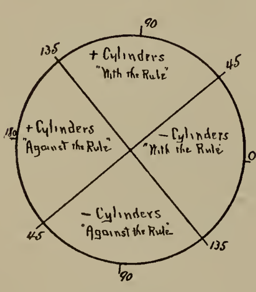


FIG. 69.

Vision in Astigmatism of Various Types.—A low degree of astigmatism is not incompatible with normal distant vision, but in the high degrees of whatever type the visual acuity is diminished, and since astigmatism is much more marked at the periphery than the centre of the cornea, vision is often very much better when the pupil is contracted than when it is dilated. This sometimes results in a patient under a mydriatic showing much greater astigmatism than before its use. Experiments have proved that the astigmatic eye sees best when the vertical focal lines fall on the retina and the individual will, so far as possible, endeavor to bring this about either by using his accommodation or by changing the position of his head or that of the object of regard, so that while the horizontal lines may be indistinct, the vertical ones shall be sharp and clear, which is a great help in reading. These vertical lines are focussed by the horizontal meridians of the cornea and the patient is able, by squinting the lids, to shut out the blurred image of horizontal lines which are refracted by the vertical meridians of the cornea and so greatly improve his vision. The student will notice that astigmatics do this constantly.

The most difficult position for reading is the reverse, in which the horizontal lines focus on the retina and the vertical ones are blurred. In this condition the letters all seem wider than normal, and if the type is fine, one letter overlaps another and all are indistinct.

Since even the slightest astigmatism tends to render some meridians indistinct, we have some difficulty in accounting for the keenness of vision often present, in other words, of understanding the mechanism of compensation. It was and still is a popular theory that in astigmatism a partial asymmetrical contraction of the ciliary muscle occurred, sufficient to change the refraction of the lens in one meridian without affecting the other, and so compensating for astigmatism as high as 3 D. Many experiments tend to negative this theory, though there are some clinical facts than can hardly be otherwise explained. Hardly more satisfactory is the hypothesis that the eye separately focusses each of the principal meridians and then unites them in a composite mental picture. Probably the best working theory is that the eye automatically secures the best vision by accommodating so that the vertical lines fall on the retina, while the blurred horizontal ones are interpreted according to the individual ability to decipher them by the aid of experience. Good vision in astigmatism is then always at the expense of ciliary effort. If this were the sole cause of the asthenopia so commonly present, it would be no greater than in hyperopia which is compensated for in the same way, while it is a notorious fact that a half dioptre of astigmatism will cause more symptoms than several of hyperopia. This is only to be explained on the ground of asymmmetrical action of the ciliary muscles or of fatigue from the continuous task of deciphering diffusion images. This plainly shows how much more important it is to correct astigmatism than simple spherical errors when both are present, especially when we remember that small errors frequently cause far more subjective disturbances than great ones. This seems paradoxical, but the patient with a high error soon learns by experience that he cannot by any effort of his own see distinctly, and gives up straining, while if the error be small the sharp vision which follows strain incites him to continuous automatic effort.

The symptoms of astigmatism depend a good deal on the variety present as well as upon the condition and age of the patient. They are of the same character as those caused by hyperopia except that they are often of greater severity.

Estimation of Astigmatism.—A large number of ingenious methods, both subjective and objective, have been devised, but it is much better that the student should have a thorough knowledge of the two or three reliable methods than to confuse himself over a large number which have become obsolete or are mere theoretical curiosities without a practical value of any kind.

By all odds the most accurate and generally useful objective method is that by *retinoscopy* as explained in Chapter IV. It has the advantage of showing the amount of astigmatism in the refractive media as a whole and not of a single medium as does the keratometer, and it is especially useful in detecting the very low grade errors which cause so much trouble and are so difficult to discover. Its disadvantages are that its mastery requires much practice, good eye sight, and perhaps a special aptitude; that its results are reliable only when the accommodation is completely under control, either by a cycloplegic or the management of the physician, and because of the handicap which peripheral refraction through a dilated pupil puts on the test. In suitable cases it should have the preference over every other method as being more accurate as well as more rapid.

The *ophthalmoscope*, as explained in Chapter III, is a valuable means of estimating astigmatism of high degree, but is absolutely useless in estimating low errors, since accuracy depends on the observer's ability to relax his own accommodation, which is never absolute except in old age. There is no certainty that the observer is looking through the optical centre of the media which would be necessary for accuracy, and moreover, he generally studies not the macular region which is devoid of distinct vessels, but the retina near the nerve head which may be on an appreciably different level. It is chiefly valuable as part of a routine examination of the fundus and as a check on other tests when no cycloplegic has been used. In astigmatism of high degree it is reasonably near the mark, and an experienced observer can even estimate the axis of the astigmatism. An oval nerve head is always suggestive of a marked astigmatism.

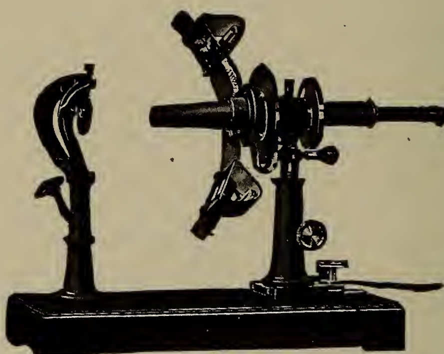


FIG. 70.

We have seen that regular astigmatism is almost always due to changes in the curvature of the cornea; consequently any means of estimating this surface in different meridians must be of practical value. Hence the usefulness of the *ophthalmometer*. Its chief disadvantages are that, since it only measures the anterior surface of the cornea, it fails to show an astigmatic error due to lenticular changes which sometimes neutralize and sometimes increase the corneal astigmatism. Hence it often fails to show astigmatism which is actually present and at other times indicates astigmatism which is already neutralized within the eye. The error of the instrument is slight, but unfortunately it is just these small errors that it is most difficult and important to find. The large errors, on the other hand, are almost invariably corneal and in these the ophthalmometer is very serviceable, especially since in these a half dioptre more or less is not relatively very important. The instrument is chiefly useful as a check on other methods of observation and particularly in cases where, for one reason or another, no cycloplegic is needed.

There are a number of instruments on the market all of which are based on the same optical principle, and though they vary in detail, an understanding of one is sufficient for all.

For all practical purposes the anterior surface of the cornea may be considered as a convex mirror and in our study of the reflections from mirrors in Chapter I, we found that that from a plane mirror was the same size as the object, while a concave mirror magnified and a convex reduced it. The reflection of a white disc or circle in a concave mirror would be perfectly round, but larger, while in the convex it would be smaller, but still round. If, however, the mirror were more curved in one meridian than the other, the reflection of the circle would be no longer round, but oval, and the greater the difference in curve, the more oval the reflection. This was noted very early in ophthalmology, and corneal astigmatism diagnosticated by the disc of Placido, the patient being seated with his back to a window while the observer held the disc in such a way that he could see its reflection in the cornea and watch for

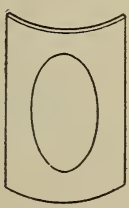


Fig. 71.

any distortion through the aperture in the centre. This would show plainly any irregular astigmatism and also high degrees of regular astigmatism, but the flattening of the circle was so slight as to be imperceptible in slight variations. The next step was to place in the aperture a prism so arranged that the observer would see a double reflection,

FIG. 72.

the edge of one disc just touching the other. If the reflections were perfectly round, by rotating the instrument one circle would seem to roll around the other with their edges in perfect contact. If, however, the reflections were even a trifle elliptical, they would separate in the meridian of sharpest curve and overlap in the flattest. Even the slightest overlapping or separation would show some corneal astigmatism and it only remained to work out the details for observing and measuring the amount of variation to give us the several excellent instruments we have to-day. In the more recent ones, instead of a white disc we have two illuminated mïres which indicate the location

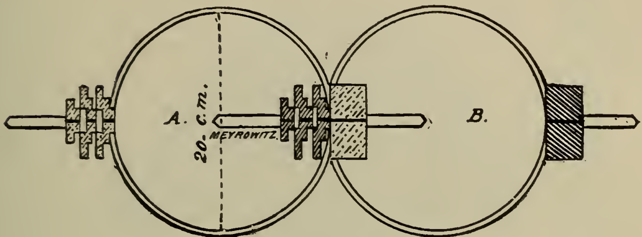


FIG. 73.

of the periphery of the imaginary circle, thus, and as the instrument is rotated, if the circles separate, the mïre with the step overlaps on the parallelogram and each step of overlap indicates 1 d. of corneal astigmatism. For purposes of estimation the barrel of the instrument contains a convex lens of known strength, so that no clear image of the reflection can be obtained till the lens is an exact distance from the cornea. The strength of the doubling prism is so arranged that at this distance a displacement of exactly 3 mm. occurs, so that when the mïres just touch, the imaginary circles evidently have a diameter of exactly 3 mm.

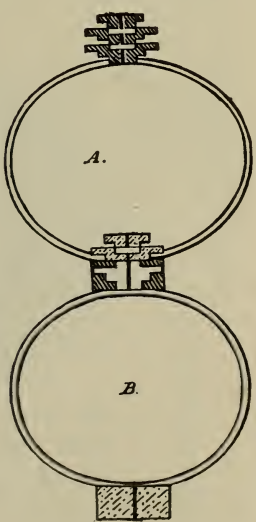


FIG. 74.

The mïres are so arranged on the arc that one or both can be moved along it till they are in exact contact. Given the size of the object as shown by the distance of the mïres from each other on the arc, the radius of curvature of the arc, which is 27 cm., the size of the reflection, which is always 3 mm. when the mïres appear to touch each other in the reflection, and we can calculate the focal length of the corneal mirror. For instance, if, when the mïres are horizontal and 20 cm. from each other on the arc, they appear to touch each other as in Fig. 73, we can estimate as follows:—

The size of the object is to the size of the image as the radius of the object is to the focal length of the mirror, or 200 mm.: 3 mm.: : 2700: ?, from which we see that the focal length is 4.05 mm., and as the focal length of a mirror is just half its radius of curvature, this cornea has a horizontal radius of curve of 8.10. Knowing the radius of curvature and the index of refraction of the cornea, it is possible to calculate in dioptres the refracting power of any corneal meridian, and if astigmatism be present to estimate it in dioptres. This, however, has been done for us by the designers of the instrument and recorded in the scale on it.

We have had occasion before to imagine the cornea as composed of two cylinders at right angles to each other. When the mïres are in the first position shown in Fig. 76*A*, and just touching, we are evidently measuring the curvature and strength of the vertical

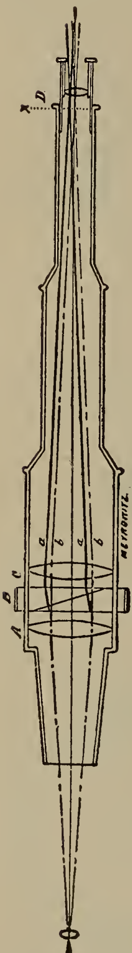


Fig. 75.

cylinder and we read it off on the dial as being 45 D. Now, when we rotate the instrument to the second

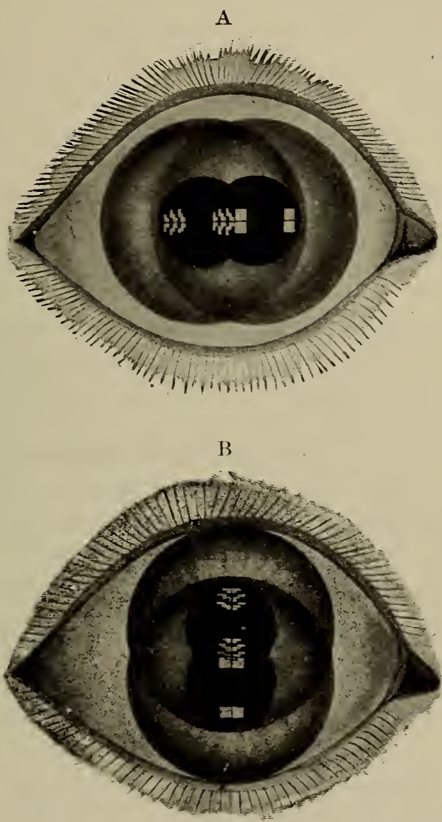


Fig. 76.

position, we are measuring the horizontal cylinder and, causing the mïres to again come in exact contact, we find the measurement to be 47 D. Evidently, the difference or astigmatism is 2 D., which can be corrected by increasing the vertical cylinder by adding a plus 2 ax. 90 or by diminishing the horizontal by adding a minus 2 ax. 180, according as the patient is hyperopic or myopic. But the two imaginary cylinders need not be at exactly 90° and 180°, and so each mïre has running through it a black line which, in the meridians of greatest and least curvature, become exactly continuous with each other, thus indicating the position of each cylinder whose strength we can measure as above.

If the anterior and posterior surfaces of the cornea were exactly parallel and its substance of the same refractive index as the aqueous, we could consider the cornea and aqueous as practically a single powerful convex lens, and the ophthalmometer would be a very exact means of estimating its power. Unfortunately, however, even the anterior surface is not regular in its curve, being more convex at the centre than at the periphery; neither is the posterior surface concentric since it always has a sharper curve (the cornea is thinnest in the centre) and not infrequently a separate astigmatism of its own which may increase or may neutralize that of the anterior surface. Then the aqueous humor has a slightly lesser density than the cornea and a very slight refraction takes place between the two. Consequently, even under ideal conditions, the method is liable to a regular error of from one-half to one dioptre, and many authorities, from a study of average posterior curvatures of the cornea correlated with experience, make it a rule to deduct half a dioptre in all cases "with the rule" and add the same amount when "against the rule."

This works out very well in a series of cases, but in the individual case it is often guess work.

If instead of looking perpendicularly through a spherical lens it is rotated on its vertical axis and looked through slantwise the effect is that it has had added to it a + cylinder, axis 90, and the more it is rotated the greater the astigmatism. The same thing holds true of the eye in which the visual line cuts the cornea to the inner side of the optic axis and is therefore not quite perpendicular to the refracting surfaces. Rays of light are therefore more strongly refracted in the axis of 90 than in that of 180, which would be equivalent to a slight astigmatism against the rule, the amount varying with the angle made by the optic axis and visual line at their intersection at the nodal point, or the angle gamma. In case of a negative angle the astigmatism would still be against the rule.

Also under the pressure of lids or muscles the entire corneal curve may vary several dioptres while one is looking at it, if the individual is nervous or his eye strained.

Another disadvantage is that the ophthalmometer gives no information as to whether the astigmatism is myopic or hyperopic, since this depends as well upon the refractive power of the lens and especially on the length of the eyeball. To be sure, one might infer that a very short radius in a sharply curved cornea would go with myopia, but if the eyeball were short, the focal point might easily be behind the retina. This is what we commonly find in hyperopia. A flat cornea would seem to indicate a focal point behind the retina, but we find this same condition in progressive myopia, in which the posterior pole of the eye has been pushed backward, so that the ophthalmometer simply indicates that one meridian is more curved than another, and they can be equalized by increasing the curvature of one with a convex cylinder or diminishing that of the other an equal amount by a concave one.

Astigmatic Charts.—These are based on the fact that in astigmatism vision is clearest in one meridian and that, if a number of lines radiating from a common centre are viewed, one set should be much blacker and more distinct than the others. In practice, however, many patients with a known astigmatism see all the lines alike, either because they cannot discriminate small differences or because they instantly focus on the lines they are regarding. The smaller the pupil the greater the difficulty. On the other hand, some neurasthenics cannot be made to see all the lines alike by any possible nicety of correction. The clock dial chart is the commonest and may be taken as the type of them all; and of the whole class it may be said that without cycloplegia they are absolutely unreliable and with cycloplegia unnecessary.

Simple Hyperopic Astigmatism.—While subjective tests should be dispensed with as much as possible in favor of objective ones in astigmatism as in other errors of refraction, the trial case test is the court of last resort, and as its use varies somewhat with the variety of error present, let us consider first a case of simple hyperopic astigmatism in a young person, the patient being seen for the first time and without a cycloplegic. The retinoscopic test reveals a simple hyperopic astigmatism of 1 D. axis 90. The ophthalmoscope shows the media clear and fundus normal, the disc very slightly oval perhaps. The ophthalmometer shows an astigmatism of 1.50 D., but without indicating whether it is plus at 90° or minus at 180°. When we seat this patient before the trial cards and test the vision in each eye separately, we find that his vision is 20/20 except that he miscalls a letter or two in many of the lines. We have already seen that, in reading, the vertical lines in the letters are more important than the others and in this case the vertical lines fall behind the retina, while the horizontal ones are directly on it. Instinctively he accommodates so as to see the vertical lines distinctly and so throws the horizontal out of focus and consequently confuses P, T and F, H, N and X. This alone should suggest astigmatism. We now place in the trial frame a + .50 at the axis 180°. This carries the horizontal strokes so far in front of the retina as to perceptibly diminish the vision, but as we rotate the glass in the frame toward the axis of 90°, he is able to focus the vertical lines on the retina without accommodating

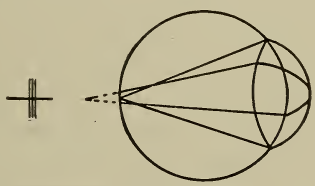


FIG. 77.

so much, and consequently his horizontal lines are not focussed so far in front, and his vision is perceptibly clearer. Right here one should change the axis of the glass a few degrees on either side of 90°, to find if possible the position of sharpest curvature, taking particular pains to see that the patient holds his head squarely. If the astigmatism is exactly vertical and the glass is improperly placed, the tendency is for the patient to tilt his head till the glass is vertical and then rotate his eye in its socket till vision is best. The glass should fit the eye, and not the eye the glass. We now place stronger and stronger cylinders before the eye, till the patient begins to complain that his sight is being fogged. In this case this will probably occur with a + .75, axis 90°. Covering this eye, we go through exactly the same process with the other and discover, let us suppose, exactly the same condition. We know that the patient has at least a dioptre of error in each eye, and so we try a + 1 ax. 90° in each, using both eyes, so relaxing the accommodation, and the binocular vision is still 20/20, though the patient plainly expresses a preference for a + .75 or perhaps a + .50. Here the wish of the patient plays an important part. If a sportsman or a surveyor with no complaint beyond a slightly indistinct vision of distant objects, it would be ridiculous to prescribe the full correction which would defeat the purpose of the consultation, and that glass should be given which gives the sharpest distant sight. If, on the other hand, the patient is a scholar or a bookkeeper who complains that his eyes tire after a period of use, and an occasional headache, it is easy to convince him with a book of Jaeger type that the + 1 ax. 90, while not so distinct for distance, is very much more restful for near work and he can take your word for it that, as he gets used to it and learns to relax his strained ciliary muscle, his distant vision will also improve.

If the patient has been referred on account of severe headache and some reflex trouble, if he has a heterophoria or there is a marked discrepancy between the subjective and objective tests which makes it advisable to get at the total error unmistakably, he should be put under a cycloplegic and examined again. This will show a slightly higher astigmatism + 1.25 by the retinoscope, the difference depending on the observer's skill and experience in controlling his patient's accommodation without atropin in the first examination, and also on the presence in the first examination of lenticular astigmatism due to accommodation which has disappeared under the cycloplegic. This is rare.

The ophthalmoscopic and ophthalmometric findings will rarely vary much. With the trial case, however, we find the distant vision has fallen materially because the patient can no longer focus the vertical strokes on his retina by aid of his ciliary muscle and so only sees the unimportant horizontal strokes. A plus sphere of 1 D. will improve this vision materially, because it brings the vertical strokes to a focus on the retina even though it blurs the horizontal ones. A plus cylinder of 1.25 D. axis 90, however, is much preferred, for it makes the vertical lines distinct while not reducing the horizontal, and gives a maximum vision of perhaps 20/20, but very likely only 20/30, owing to the dilated pupil and consequent dazzling and peripheral refraction. If we rotate the cylinder either way from the vertical even a little, the vision is somewhat lessened and the patient complains that the letters are tipped to one side or the other slightly.

If we increase the cylinder beyond + 1.25, the vision is materially reduced, also if we place even a + 25 sphere over the cylinder. We find the same condition in the other eye. If the patient's condition is such that we wish him to wear the full correction, whether it reduces his vision or not we order it, but unless one has the confidence of his patient completely, it is advisable to continue the cycloplegic for several days after the glasses are first put on, as otherwise the patient will constantly see better without them and either desert entirely or discard the glass at every opportunity. If for any reason the patient cannot use a cycloplegic, I never hesitate, if he is intelligent and I have his confidence, to order what I think his full correction, no matter what the effect on distant vision, but it is often a hazardous experiment. The higher the astigmatism, the more it is ordinarily permissible to leave uncorrected. For instance, if a patient at the first examination and without atropin accepts a + 2.50 axis 90° and the subsequent test under cycloplegia shows a total astigmatism of 4.50, the glass ordered should be a 3.50 or even 4, depending somewhat on the patient's age: the older, the higher the acceptance. Patients with cylindrical lenses should always be cautioned about the probable apparent effect of these glasses, which for a time seem to distort objects and distances in proportion to the strength of the glass. They seem to be walking up hill or the houses threaten to topple into the street, and they misjudge distances badly. This all disappears in a few days' time.

Compound Hyperopic Astigmatism.—Let us suppose a young patient whose retinoscopic test without cycloplegia is + 3 + 3 axis 90°, while the ophthalmometer shows a refractive strength of 42 D. at 90° and 45½ D. at 180°, thus indicating an astigmatism of 3 D. "with the rule." At the test card the vision is considerably reduced since the patient has to accommodate 3 D. to see the horizontal strokes in the letters and 6 D. the vertical ones, and the astigmatism is so great that when either set is clear the other is too much obscured for accurate guessing. We are not surprised to find the vision 20/70 in each eye. We place a convex cylinder of 1 D. before the eye and rotate it to the axis where it gives the best result, which we find to be at 90°, and by gradual stages we increase its strength to 2 D., though the patient says he can see a trifle clearer with + 1.50. As the strength of the cylinder increases, the patient becomes more intolerant of any deviation from the axis 90°. The use of this cylinder corrects a large part of the astigmatism and enables him by accommodating about 3 D. to focus both the horizontal and vertical strokes so nearly together on his retina as to improve his vision up to possibly 20/30. If now we place in front of the cylinder a convex spherical lens, we do not necessarily improve his vision, but give him the same vision without compelling him to accommodate, and we increase the sphere till it begins to reduce his acuity. Probably he will not be able to relax so as to accept over + 1.50. We have then got him to accept a + 1.50 ⌒ + 2.00 axis 90° in each eye alone, while we feel confident that, if he could relax completely, it should be nearly + 3 + 3 axis 90°. By using both eyes together we can certainly increase the sphere and possibly

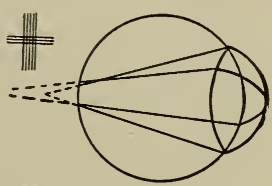


FIG. 78

the cylinder without reducing his vision and can get him to wear a combination of + 2 + 2 axis 90° in each, = V 20/30. If he consults us because of headache or tired eyes, we prescribe the strongest possible combination, confident that it will be more of a comfort for near work than for far. But if the glass is for the improvement of distant sight, he will be much better pleased, if the spherical element is reduced a little so as to let him exercise his very efficient accommodation a little. If it seems best to examine the patient under atropin, if our retinoscopy is accurate, he ought to obtain his maximum vision with + 2.75 + 3 axis 90 in each eye. When we test his vision without glasses, we find it greatly reduced, since he no longer has the asistance of his accommodation perhaps 20/200 in each eye. For the same reason neither the cylinders nor spheres alone cause the improvement they did in the previous examination. The best way is to try him at once with the full retinoscopic correction and after testing the vision make slight changes in both sphere and cylinder till the combination is found that gives the best vision. Owing to the dilated pupil one would hardly expect to get as good a maximum vision as at the first test. If the patient prefers a combination within a quarter of a dioptre of the retinoscopic finding, there is every reason to be satisfied; but if the beginner gets within a dioptre, he need not be discouraged. If, however, there is a marked discrepancy, it indicates a mistake in retinoscopy, or that the cycloplegia is incomplete, while children often memorize a test card and seem to see much better on a familiar one than they really do. Having estimated accurately the refraction, the final prescription depends on the judgment of the surgeon and the object sought by the patient. Get as near to the ideal as possible, particularly in the cylinder. The general rule in hyperopic astigmatism, whether simple or compound, would be: prescribe the strongest convex cylinder that the patient will accept without cycloplegia in any case and go beyond this if circumstances make it advisable. Be sure that the patient holds his head perfectly straight during all tests and arrange the axis of the cylinder in the position which gives the sharpest vision without any tipping or distortion of the test letters, even when it does not exactly agree with the axis indicated by the ophthalmometer and the retinoscope. After ascertaining the strongest cylinder, place over it, if possible, the strongest sphere which does not actually reduce vision.

Myopic Astigmatism—Simple.—Suppose a young person with a simple myopic astigmatism with the rule of 1 D. as shown by the retinoscope and ophthalmometer.

When seated before the test cards, the vertical strokes in the letters are focussed on the retina, while the horizontal ones are focussed in front of it. If the error was a very slight one, the patient could see enough of these latter to guess very accurately at the letters; if the error is greater, vision is correspondingly uncertain, only a series of vertical black lines being perceived. Accommodation only makes matters worse by focussing both meridians in front of the retina. If we make the mistake of trying spherical lenses first and place before the eye a — 1 D., vision is improved,

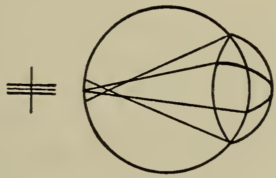


FIG. 79.

because the horizontal strokes now focus on the retina and the vertical behind it, when by a slight exercise of accommodation they can be seen. In other words, we have changed a simple myopic into a simple hyperopic astigmatism, which has the advantage of giving him better distant vision, but causing him more strain. If, however, we substitute a concave cylinder axis 180°, we carry back the horizontal focal line till it falls exactly on the retina without affecting the vertical which is already there. Consequently we have a maximum of vision with a minimum of strain. If the strength of the cylinder is increased beyond the full correction, the focal line is carried further behind the retina and the tendency is for the individual to strain his accommodation to bring it forward again: hence moderate over-correction does not necessarily reduce vision. In simple myopic astigmatism, however, this accommodation blurs one meridian in exactly the proportion that it clears the other, and so reduces the vision again, and over-correction is not as likely as in compound myopic astigmatism.

IN COMPOUND MYOPIC ASTIGMATISM, since both principal meridians focus in front of the retina, the vision is very much reduced. Suppose the objective tests show a myopia of 2 D. with 2 D. of astigmatism axis 180°. If we make the mistake of beginning with spherical lenses and place a — 2 sph., we shall find the vision much improved; if we increase it to — 4 sph., the horizontal focal line has been carried back to the retina, while the vertical ones are behind it. In other words, the astigmatism is now a simple hyperopic of 2 D. with which a young person may have a vision of 20/30. Evidently the glass would improve vision, but would cause strain. The best way is to begin with the cylinder, gradually increasing the strength, and searching for the axis which gives the best vision, and when increase of strength no longer causes improvement in vision, to add concave spheres of gradually increasing strength. If the combination of lenses which gives the best distant vision nearly coincides with the result of the objective tests, it may be prescribed, but such is rarely the case, since the patient almost invariably obtains the maximum vision with an over-correction which allows him to accommodate. A moderate over-correction of the spherical element does probably no harm in many cases, but the same cannot be said of the cylindrical which should be as exact as possible. In myopic astigmatism, as in

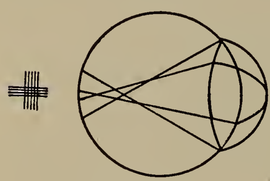


FIG. 80.

simple myopia, the rule is to find the *weakest glass* which will give the best vision. For this reason the great majority of myopes should be examined under cycloplegia. In contradistinction to the hyperope, who always sees poorly under atropin, the myope whose vision is best with accommodation relaxed not infrequently sees better and so submits more gracefully to the necessity. Under these conditions the subjective and objective tests should correspond within a fraction of a dioptre, and it only remains to decide on the glass to be prescribed.

In low and moderate errors it is certainly best to order the full correction for constant use and it is best put on while the patient is still under cycloplegia. In very high myopia and especially when the patient has never worn glasses, it is sometimes advisable to under-correct for a time and even prescribe a weaker glass for near work. This is a matter of individual judgment, and my experience is that surgeons who are themselves myopic commonly believe in under-correction. The astigmatism, however, should be fully corrected and the reduction, if made at all, taken from the spherical element.

Mixed Astigmatism can rarely be satisfactorily corrected without atropin. Suppose a patient whose error is + 2 axis 90° with — 2 axis 180°. Plus spheres only reduce his already very bad vision. If, however, we try minus spheres, the vision immediately improves. With a — 2 sphere, for instance, the horizontal strokes focus on the retina, while the vertical ones focus behind it. In other words, we have changed the mixed astigmatism into a simple hyperopic astigmatism which is to be corrected by placing over the concave sphere the strongest convex cylinder axis vertical that the patient will accept. The difficulty is, however, that the patient without cycloplegia invariably demands an over-correction of his myopic meridian and an under-correction of the hyperopic. This patient under atropin should see best with $-2 \bigcirc +4$ axis 90°, while without it he would have a much inferior acuity with about $-3.50 \bigcirc +4$ axis 90°.

It is much the best plan to examine all cases of supposed mixed astigmatism under atropin, because in many of them the myopic element disappears with cycloplegia. Except in extreme cases the full atropin correction should be ordered.

The problem presented in the correction of astigmatism is not difficult so long as the error is large enough to be detected. In these cases the retinoscopic appearances are characteristic and plain, the work at the trial case is easy because the patient definitely prefers a certain glass at a fixed axis, and the regular error of the ophthalmometer is so small in proportion as to be more or less negligible.

Fig. 81.

The detection of the very low degrees of astigmatism is very much more difficult, the difficulty increasing proportionately with the minuteness of the error and unusual positions of the axis.

Many authorities argue that errors so small as to almost defy detection are of no importance and do not require correction, and doubtless this is true in many cases. When we are searching, however, for possible causes of reflex troubles manifesting themselves perhaps in other portions of the body, these small errors are of much greater importance.

In my own experience I have often noticed that some of the most brilliant results followed the detection of astigmatism of less than half a dioptre in eyes that were otherwise emmetropic.

Work of this kind cannot be done without a cycloplegic and is often very difficult with one. Under cycloplegia the retinoscope may show an astigmatism of less than half a dioptre but the presence of spherical aberration often makes the result very uncertain both as to amount and axis. The ophthalmometer is not more helpful for it was never intended for measuring such small fractions. It simply indicates that an error, if present, must be a very small one.

The whole thing must therefore be worked out at the trial case with much patience, aiming to discover the combination which gives the sharpest and clearest distant vision. In these low astigmatisms it is often very difficult to decide on the exact axis of the cylinder, since the patient has almost the same visual acuity when the axis is changed ten degrees or more to either side. One can rotate the cylinder each way till the patient is sure his vision is slightly lessened and then take the meridian half way between as the axis. Here, if ever, the astigmatic chart is likely to be useful as a check on other measures, since the pupil is widely dilated and the accommodation at rest. The estimation of astigmatism is facilitated by the "cross cylinder" consisting of a weak + cylinder combined with a weak — one, their axes being at right angles. When held in front of the trial glasses it increases one meridian and decreases the other, while the patient can note the result much better than after a slower change of the trial lenses themselves.

CHAPTER IX.

PRESBYOPIA—ANISOMETROPIA—APHAKIA.

Presbyopia.—We have seen in our previous study of the process of accommodation that in extreme youth when the lens is very elastic and can assume almost a spherical shape, the individual can get a sharp image of an object very close to him and that the nearest point which is consistent with distinct vision is known as the punctum proximum. As the years increase, the lens undergoes a physical process of sclerosis, beginning at its centre, which gradually diminishes the ability to become spherical and consequently the near point gradually recedes from the eye and in extreme old age may reach infinity. It makes no appreciable difference to a person whether the near point is at four or six inches, but there is a point beyond which it cannot recede without causing inconvenience and disability, and when this point has been reached, presbyopia, or old sight, is said to have set in. The age at which this occurs depends on a number of conditions. The laborer suffers no inconvenience till it recedes three or four feet, for that is his ordinary working distance, while the engraver or lace maker who works steadily at small objects at ten or twelve inches is inconvenienced very early. Health and race are also factors. The robust, healthy person may retain the elasticity longer than normal, while the individual who matures early is apt to have a premature sclerosis of the lens.

That we may have some standard we assume that presbyopia begins when the *near point* has receded so far that the individual can no longer readily distinguish fine print at the distance of ten inches, and to secure uniformity Jaeger long ago introduced a series of test types beginning with a very fine and progressing by gradual steps to a very coarse print. These gradations were not scientific, because they were printed from type of various sizes as found in the ordinary printing office, and the steps from one set to the next were not by any means equal, but the objections were more theoretical than practical. Later on Snellen introduced a type on the same principle as his large wall type, each letter being of such size as to subtend a definite visual angle. This is more scientific, but has failed to displace the Jaeger type and for practical purposes they can be used interchangeably.

The nearest point at which No. 1 Jaeger can be read is the individual's near point, and when in the process of age the point recedes beyond ten inches or 25 cm., presbyopia has begun. This requires exactly 4 D. of accommodation and consequently when the amplitude is less than this, the patient is presbyopic. No individual can continuously employ his entire accommodation without undue fatigue and experiments show that about one-third must be kept in reserve. Therefore, the emmetrope of 40, who can read No. 1 Jaeger at 10 inches for a few moments only, can read ordinary print at the usual reading distance of 13 inches without tiring, since this requires only 3 D. of accommodation.

In the table of amplitudes (Fig. 38) given years ago by Donders we see that the emmetrope at the age of 40 has 4.5 D. left and hence is on the verge of presbyopia, upon which he is generally well entered by 45.

The presbyope first seeks to compensate for his defect by pushing his book further away, which makes the type look a trifle smaller, but more distinct. Next he begins to require larger print which can be held further away without looking smaller. Reading at night or in bad light allows his pupils to dilate and so increase the size of diffusion circles with consequent dim vision, so that he sees best with the light so placed as to fall directly on his eyes, contracting the pupil. This type of presbyopia is not painful, because it is due to simple lack of elasticity in the lens. There is another form due not to deficient elasticity, but to defective power in the ciliary muscle which entails the same strain as does hyperopia and astigmatism. This is not really presbyopia, but subnormal accommodation, but its effect on the visual capacity of the patient is the same, plus pain. The two may occur together and their treatment is the same, but the latter often develops earlier in life than true presbyopia, is not always a constant condition, since it may be the result of fatigue or ill-health, and may disappear with the improvement of the muscular tone throughout the system. It is to be remembered that the distant vision of the presbyope may be normal.

The refractive condition of the patient plays a very important part not only in influencing the age at which presbyopia begins but the disability it entails. For instance, a hyperope of 3 D. requires that amount of accommodation for distant vision alone and when this is added to the amount necessary for clear vision at ten inches, it is evident that 7 D. is required and that as soon as his accommodative power falls below that, presbyopia has begun. By referring to the table we see that accommodation has fallen to 7 D. at the age of 30.

Myopia on the other hand postpones the onset of presbyopia. For instance, a myope of 4 D. has his far point at ten inches and can read the finest print at that distance without accommodating at all. Consequently he will never become presbyopic.

Astigmatism very often complicates presbyopia. When hyperopic and of high degree, it diminishes the clearness of near vision, and since it calls for abnormal accommodation it causes early presbyopia. The lower degrees have not so much effect in hastening the approach of actual presbyopia, but from the fruitless strain they put on the ciliary muscle in near vision, they develop an intolerance of near work, which is practically a presbyopia due to insufficient accommodative power.

In myopic astigmatism the patient approaches his book till the myopic meridian focusses on the retina and then focusses the other by straining his ciliary muscle exactly as in hyperopic astigmatism. Therefore, myopic astigmatism, whether simple or compound, does not postpone presbyopia to the same extent as does simple myopia, and is often associated with accommodative asthenopia and retinal fatigue.

THE TREATMENT of presbyopia consists in ordering a convex glass strong enough to bring the near point up to ten inches. This will vary in strength with the age and refraction of the individual. If he is emmetropic at the age of forty, he has a power of 4.50 D., which is more than enough without a glass. At 45 his power has fallen to 3.50 and he needs at least half a dioptre more added in the form of a convex lens. At fifty his power has fallen to 2.50 D. and needs to be supplemented by a + 1.50 convex lens. At fifty-five a + 2.50 is needed, at sixty a + 3.50. Theoretically a presbyopic correction of about 4 D. should be all that would ever be necessary for an emmetrope, but as the emmetrope reaches the age of about sixty-five, he becomes slightly and increasingly hyperopic through changes in his lens.[1]

Roughly speaking then, the presbyopic correction of

[1] The lens is composed of concentric layers of varying refractivity, so that light undergoes refraction every time it passes from one layer to the next, but with age this layer becomes homogeneous, and the total refraction of the lens is somewhat reduced.

an emmetrope is about 1 D. for each five years after reaching forty. It is important to remember that the presbyopic glass, while it brings the near point closer, also does the same with the far point, and that as accommodative power grows less and less the flexibility of the eye does the same, so that in selecting a glass, one has to take into account the usual working distance. For instance, at forty-five with a + .50 glass, the patient can by relaxing see distinctly at 2 metres, or eighty inches, and by accommodating can also see distinctly at 10 inches or at any point between the two. At sixty-five, however, with a + 3.50, he cannot see beyond eleven inches, nor closer than 10. Consequently, the older the patient the more carefully one must consider the distance at which he works. The carpenter or blacksmith at sixty-five could not wear the full correction because he cannot bring his work so close to his eyes. Either would be more useful with a + 2, while the student or the sewing woman, whose work is always close at hand, needs the full amount.

If the patient is not emmetropic, he must be made so by glasses before estimating his presbyopia. In other words, we add to his full correction for distance about 1 D. for every five years of age after forty, which will generally enable him to read No. 1 Jaeger at ten inches. If it does not, one would suspect that the estimation of the distant vision was not correct, that a misstatement of age had been made or that there was some defect in the eye in the nature of a paralysis of accommodation or some change in the media.

If the patient be hyperopic or astigmatic, the full correction for distance will generally be sufficient for near work as well till between forty and forty-five, after which two pairs of glasses must be used, one for near and the other for distant vision. The latter will require little, if any, change for many years, but the former will need to be increased at frequent intervals depending on the age and the rapidity of the failure of accommodation. Some individuals can go four or five years without change, if the full correction has been made and the work is not arduous, while many others are better for a slight increase every year or two.

In myopia and myopic astigmatism the same rule holds good: the convex glass for near, neutralizing the concave distance glass to which it is added. For instance a myope of 2 D. at forty-five years would theoretically wear $-2 + .50 = -1.50$ D. for near work, which would be gradually diminished, as time went on. Practically, however, such a myope may be without any glass at all up to fifty-five or sixty and would certainly object to wearing glasses for near work. In case of higher myopia of 8 or 10 D. the patient's far point without glasses would be so close to the eye, 4 or 5 inches, as to be very fatiguing. If young, he would wear his full correction for both near and far, while if older, his presbyopic correction would take the form of a reduction in the strength of his glass.

The ordinary presbyopic spherical lenses should be tilted forward so that, in his ordinary reading position, the patient looks perpendicularly through the lens. Otherwise it has the effect of a weak cylinder added to the sphere. For this reason some presbyopes with a low astigmatism against the rule are more comfortable without the cylinder as they get the same effect by looking obliquely through the lens.

A very convenient form of glass in presbyopia is the so-called bifocal in which the correction is cemented on to the lower half of the patient's distance lenses, so that when the patient looks off into the distance, he is using the upper half and when he looks down as in reading he looks through the stronger lower half. Such lenses require very careful optical adjustment, so that the patient may not be conscious of the dividing line between the two parts and some nervous people never can learn to be comfortable in them. When properly adjusted, however, he cannot strain his accommodation for near work or for distance, and it is possible to increase the presbyopic correction from time to time without changing the distance glass.

Instead of the cement bifocal one of the various forms of ground bifocal may be used, the reading segment of which is practically invisible. Patients who do not need distance glasses and whose work requires both far and near vision, can have the upper part plane or have it cut away entirely, wearing a crescent shaped "clerical" or "pulpit" glass. In myopes this is often reversed, the upper part of the lens being retained for distance, while the lower part is cut away.

Anisometropia is the term used to describe the condition of eyes whose refraction is unequal. In the narrow sense of the word no two eyes are exactly alike, but the term is applied only when the difference is great enough to be of practical importance.

Anisometropia is often a congenital condition, one eye being smaller or with differently curved refracting surfaces, and not infrequently the inequality of the eyes is associated with unequal orbital or cranial growth. It may be also due to the varying progress of disease as in myopia, to operation or injury, as after cataract extraction, displacement of the lens, displacement of the pupil and changes in the corneal curvature and other similar causes.

When uncorrected, it entails a series of symptoms depending on the variety and degree of the refractive difference which are not infrequently replaced by others just as annoying after correction. The condition therefore often calls for the exercise of judgment and skill as to whether the individual will benefit at all from correction and, if so, whether the correction should be complete or only partial.

Symptoms.—If the refractive difference is a material one, the image formed on one retina must be very much more indistinct than that formed on its fellow. Many authorities assume that some individuals, if not all, can compensate for this ametropia and make the refraction of both eyes the same by an equal contraction of the ciliary muscles. In this case true binocular vision might be present. On the other hand there is much evidence that in many other cases the ciliary muscles must receive the same amount of innervation and that any change in the refraction of one eye must be accompanied by an equal change in its fellow. In such cases the retinal image in the worst eye must be not only dimmer, but must also vary slightly in size or form from its fellow, and while the brain has learned to form tolerably correct judgments from superposing one on the other, and it is a great help in stereoscopic vision, still vision is not in the true sense binocular. When the anisometropia is a slight one, the difficulty is negligible, but in many other cases binocular vision is maintained at the expense of constant ciliary effort, or the brain is fatigued by a continuous series of unconscious mental judgments as to the apparent and actual size, shape and distance of objects. Naturally this is often accompanied by the varied symptoms of ocular and nerve fatigue.

In other cases of greater inequality the retinal images are so dissimilar that the fusion sense is either weakened or entirely abolished. Such patients very easily develop strabismus.

It occasionally happens that the patient can use one eye for distant and the other for near vision. For instance, if one eye has 4 D. of hyperopia and its fellow an equal amount of myopia, the first would certainly be used for distance, while the other could be used for near work without any accommodation at all, but the vision would be in no sense binocular.

The results of correction of anisometropia must also be borne in mind. In suitable cases of low degree in the young, distinct vision in both eyes results and the retinal images being sharp and equal in size and shape, perfect fusion occurs at once. In others the effect of the correction is in itself a source of confusion and annoyance. For instance, a patient has become accustomed to base his mental estimates on the distorted image of an astigmatic eye. He knows that objects which are to a certain extent oval, are actually round, and they finally cease to appear oval and the distorted image impresses him as regular. Now if this astigmatism is corrected so that the retinal image is actually correct, he has to revise his whole set of visual judgments. If he is young and plastic, this is easily done, but at the other extreme of life it is a great annoyance.

The effect of lenses on the apparent size of objects is also to be remembered. For instance, if one eye be emmetropic, while the other is highly myopic, the concave glass being a sensible distance from the eye makes the image on the retina actually somewhat smaller than in the other eye and apparently very much smaller indeed. The patient therefore, has two images which are sharp and distinct, but of notably different size, and he has great difficulty in fusing them. If he has any latent muscular error, he has at once a diplopia which will result in fusion by straining or a squint by the suppression of one image.

If the ametropic eye has a high degree of hyperopia, the convex lens causes an apparent increase in the size of the object of regard, and the same difficulty is met with. Hyperopia, however, being usually of low degree, is not often a source of trouble except after removal of the lens in cataract, which requires a correction of about 10 D.

In this condition, if the other eye has good sight, the patient is often much more at ease if the aphakic eye be left uncorrected and used, not for central, but only for peripheral vision.

Another source of trouble is the prismatic effect of strong lenses. A myope in converging looks through his concave glass to the inner side of the optical centre and it has the effect of a very strong prism, base in, the converse being the case in the hyperopic eye. When the patient looks above or below the centre of a strong lens, the prismatic action is often enough to cause an actual diplopia. It can be readily seen that the correction of anisometropia is a matter calling for the exercise of skill and judgment.

In young persons, where the inequality is of low degree, it can usually be accomplished easily and will prove very beneficial, and even when the inequality is great a persistent effort should be made to secure binocular vision.

In young adults whose mental habits are more firmly fixed, the prognosis is not by any means so good, while in the middle aged and the old, binocular vision in marked anisometropia is almost hopeless, and correction of the worse eye so likely to be the cause of fruitless annoyance as to be better left untried.

Aphakia is the refractive condition of an eye whose lens has been removed or dislocated. In this condition the accommodation power of the eye has disappeared entirely. For distant vision the human lens in a normal eye can be substituted by a convex lens of about 10.5 D. worn at the usual spectacle distance. In both hyperopia and myopia of the refractive type, the measurements of the eye being otherwise normal, approximately the same correction will be called for. In axial myopia, however, as we have seen in another chapter, the effect of the removal of the crystalline lens varies widely according to the amount of elongation of the eye ball and the distance of the lens from the retina. The distance of the correcting lens from the eye is also a factor. Cataract extraction in high-myopia may therefore cause a refractive change seldom less than 15 D. and occasionally as great as 25 D.

The fitting of cataract glasses differs somewhat from that of ordinary glasses.

Theoretically the aphakic eye being without accommodation should be fitted as exactly by retinoscopy as the atropinized eye, but practically it often happens that the pupil is small or that there are extensive membranous remains with an opening large enough to give the patient clear vision, but altogether too small for successful retinoscopy.

The same difficulty also occurs in the estimation of refraction by the ophthalmoscope, though in many cases it is possible.

The ophthalmometer of Javal is a very reliable means of estimating the astigmatism, since in the absence of the lens it must be corneal.

The usual section of the cornea in cataract is made upward, and in the process of healing the flap overlaps, causing a flattening of the vertical meridian with an astigmatism against the rule, which may amount to 5 or 6 D. or even more. A large part of this usually disappears within a few months; hence the first glasses are to be regarded as a temporary expedient. The ophthalmometer, therefore, affords a very accurate method of estimating not only the amount of astigmatism, but also its axis.

When it comes to the trial case test, the patient should be given the glass or combination which gives him the best vision, since he has no accommodation and therefore cannot strain the eye. The patient must be told that he has to learn to use his eyes all over again. Familiar objects all look larger than before, and since the patient knows from experience how they ought to look, they impress him as being closer than they really are. He must be cautioned to move his head rather than his eyes in looking at things, so as to look through the centre of his lenses and avoid the cylindrical and prismatic effect, which is considerable.

Being without any accommodative power, the aphakic eye must have an additional correction for near work. For reading, which is generally done at ten inches a + 4 D. should be added to the distance correction, many patients being able to wear bifocals with comfort. If the working distance be somewhat greater, the correction should be correspondingly less. The patient can see distinctly at only one distance, but he can, by sliding his glasses down on his nose, increase their power and so obtain a limited accommodation effect. It is not always desirable to correct the entire astigmatism against the rule, since the patient by looking obliquely through a spherical lens gets the same effect and is better pleased.

When only one eye has useful vision, a reversible spectacle is very convenient, which contains the distant correction on one side and the near one on the other.

CHAPTER X.

BINOCULAR VISION.

We have hitherto treated the function of vision as though it were carried on with one eye, only incidentally referring to the fact that we have two.

We have now reached the point where we must take cognizance of the fact that human vision is binocular and that the instinct for binocular single vision is imperious and requires a delicate and far-reaching co-ordination of nerve, muscle and brain. So imperious is this desire and so delicate the mechanism, that obstacles which impede or prevent binocular vision not only diminish the visual capacity, but also often cause a complicated train of reflex symptoms in other parts of the body.

In one eye alone the only object which is seen with absolute distinctness is that whose image is formed at the macula; consequently, in order to see distinctly the eye is so directed that this image falls on the macula, whence the visual impression is transmitted to the brain. In using both eyes together, if they be equally good, they must be so turned that the image of the same object is focussed on each macula, when both transmit the same impression to the brain and satisfactory vision results. If, however, the eyes do not co-ordinate, the brain receives the impression of the object on one macula, but also at the same time an equally distinct impression of whatever other object happens to focus on the other macula at the same time. One learns in time to make a choice between the pictures and suppress the other, as in using the microscope with both eyes open;

but till this is done, endless confusion is caused. Evidently the two maculæ, if they receive the same image and transmit to the brain a single impression, may be said to be "corresponding" or "identical" points. If we gaze straight in front, any object to the right falls on the left side of each retina, but as the brain receives the impression of only one, the points on which these images fall must also be identical points. The same is true of objects to the left or above or below the direction of the gaze. Evidently each retina is made up of points which correspond or are identical with points in the other, and we can easily determine these points by tracing the paths of light which fall on them from any object, the *corresponding points* of the two retinas being those on which the two images of the object fall when the visual axes converge at the object. Tracing this out, we find that the upper half of one retina corresponds to the upper half of the other. The lower halves correspond also, while the nasal half of one corresponds with the temporal half of the other.

If the visual axes are not so directed that the image of the object of regard falls on identical parts of both retinæ, a double picture is formed. For instance, if the object is a candle flame, which is focussed on one macula, but falls on some non-identical part of its retina of the other eye, the brain receives from the macular image the impression of one flame which is sharp and distinct, while from the other eye it gets the impression of an entirely different flame which, being received from a less sensitive part of the retina, is less distinct, but nevertheless very confusing. Since in the ordinary movements of the eye we see images singly, it is obvious that the movements of the eyeballs must constantly be so coördinated that the images of external objects fall on corresponding points of the two retinæ. That we may have a clear conception of the way in which the coördination is obtained, we must study the movements of the eyeball and the muscles which control them.

The eyeball in its orbit corresponds very closely to a ball and socket joint in which the only possible movements in health are those of rotation, and these rotary movements are carried on about an imaginary point in the centre of each eye, called the centre of rotation, which has been experimentally located in the vitreous about 13.5 mm. behind the anterior surface of the cornea. It is, of course, quite different from the optical centre or nodal point of the eye.

The imaginary line passing from the macula through the nodal point of the eye to the object of regard is known as the *visual line* of the eye.[1] When we look straight forward, the visual axes are parallel, and when we look at an object nearer than infinity, the visual axes converge more and more as the object of regard is nearer. The horizontal plane in which the visual axes lie is called the *visual plane,* and the vertical plane midway between the eyes is called the *median plane.*

The *primary position* of the eyes may be described as that which is assumed when, with head erect, we look at an object infinitely distant on the horizon, when the visual axes will lie in the horizontal plane and be parallel to each other and the median plane. All other positions of the eye are secondary positions. We can conceive of three

[1] This is not to be confused with the optic axis which is the line on which the cornea, lens and other dioptric media are centered. This passes through the summit of the cornea, the nodal point of the lens, and may or may not pass through the macula. In the perfect eye the optic axis would coincide with the visual axis, but it very seldom does so exactly (Fig. 30).

possible movements or combinations of movements of the eyes: first, lateral motion in and out as in adduction, abduction or convergence; second, vertical motions in raising or lowering the eyes; or combinations of the lateral and vertical movements. If we examine carefully, we shall see that no voluntary combination can be executed which causes the image of the object of regard to fall on portions of the two retinæ which do not correspond; in other words, we cannot make any motion of the eyes voluntarily which results in diplopia. We can move them to right or left and up or down in many combinations, but we cannot diverge them or direct one up and the other down, since these images would fall on dissimilar parts of the retina, and diplopia result.

Some of these motions we can make involuntarily, but only when conditions are so arranged that no diplopia results. For instance, if we place prisms before the eyes in a suitable manner, we can cause the eyes to diverge, laterally or vertically, to a certain extent, because the prisms change the position of the images so that they continue to fall on "identical" portions of the retina in spite of the divergence.

There is a third motion of the eye, that of rotation about its optical axis as a wheel rotates on its hub. If the two eyes are rotated wheel-fashion, so that their vertical planes are inclined toward each other above (*intorsion*), the image of the object of regard, a vertical line, for instance, instead of falling on the vertical meridian of each retina, would lie in the nasal half of each below, and in the temporal half of each above. These are not corresponding points in either case and the vertical line would appear like an oblique cross. Similar phenomena would occur if the vertical planes were inclined away from each other, or if one were rotated in either direction while the other remained perpendicular. If, however, both planes are rotated *equally* in the same direction, the image continues to fall on identical areas and no diplopia results. In other words, the perpendicular planes of the eye, if rotated, must be kept perfectly parallel to avoid diplopia. Inasmuch as we do not regularly have diplopia, it is evident that these planes are kept parallel throughout all the various movements of the eyes. The numerous possibilities of diplopia in binocular vision indicate not only the imperious instinct for single vision and the very delicate muscular and nerve

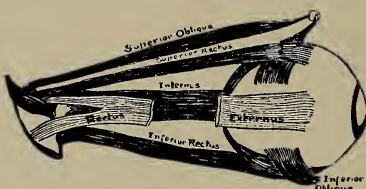


FIG. 82.

coördination necessary to maintain it, but also indicate the tremendous struggle on the part of nature to maintain it when congenital or acquired obstacles are interposed.

Now let us consider for a moment the different muscles which move the eyeball, their action and the means by which they are coördinated. Each eye is supplied with four straight muscles and two oblique. The straight muscles all have their origin from the bony walls at the apex of the orbit. The *internal rectus* passes forward horizontally along the inner wall and is inserted into the sclera about 5.5 mm. from the margin of the cornea, the line of insertion being vertical. Its action is to turn the cornea horizontally toward the nose. The *external rectus* is a much smaller muscle which passes horizontally forward to the outer side of the ball and is inserted into the sclera 6.9 mm. from the margin of the cornea. Its action is to turn the eyeball horizontally outward, being directly antagonistic to the internus. The *superior rectus* is a small muscle which runs forward and outward and upward over the eyeball to be attached obliquely to the sclera in the median line 7.7 mm. from the upper edge of the cornea. Its action is evidently not as simple as those of the internus and externus, as can be seen from Fig. 83. When the eye

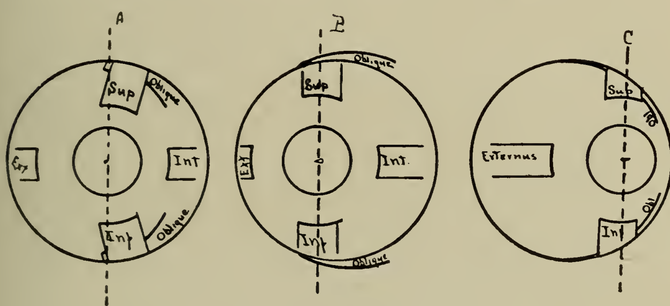


FIG. 83.

is turned outward till its axis is directly in line with the course of the muscle (Fig. 83-*B*), the action would be simply that of turning the cornea upward in that same line. If the eye is looking directly forward (83-*A*), it not only elevates the cornea, but since the insertion is in front of the equator, it turns the cornea toward the nose at the same time. If the eye be already turned strongly toward the nose (83-*C*), its chief action is to rotate the eye wheel-fashion, tipping the top of the vertical plane inward and backward, an intorsion. In almost every position of the eye the action of the superior consists of varying combinations of elevation, adduction and intorsion.

The *inferior rectus* passes from the common origin forward along the floor of the orbit slightly down and out, and is inserted 6.5 mm. from the lower edge of the cornea in the vertical plane. Its action is also a complex one. When the eye is directed outward (Fig. 83-*B*), so that the vertical plane is in line with the course of the muscle, it simply depresses the cornea and is a direct antagonist to the superior rectus. When the eye is directed straight forward (Fig. 83-*A*), however, it not only depresses the cornea, but adducts it, in which it assists the superior and internus. When the eye is strongly adducted (Fig. 83-*C*), it has a rotary action on the cornea, tipping the top of the vertical plane outward and forward, extorsion. The action of the inferior rectus then consists of varying combinations of depression, adduction and extorsion.

The *superior oblique* rises from the common origin and passes along the wall of the orbit to the trochlea or pulley just inside the upper inner margin. The trochlea consists of a firm fibrous loop, in which the tendon of the muscle can slide back and forward and from this the tendon bends backward and outward at an acute angle and is inserted obliquely in the mid-line of the sclera, but behind the equator. We shall understand its action better, if we imagine it arising from the trochlea, since that is the direction of its traction. If the eye be turned strongly in, so that the vertical plane is in line with the course of the muscle, since it is inserted behind the equator in the posterior half of the eye, its action is simply that of a depressor of the cornea (Fig. 83-*C*). When the eye is directed straight forward, by virtue of its posterior insertion, it not only depresses the eye somewhat, but also abducts it and intorts it (Fig. 83-*A*). From its insertion its chief function is torsion (Fig. 83-*B*).

The *inferior oblique* rises from the inner lower margin of the orbit, passes outward, backward and downward and is inserted near the mid-line of the sclera, but behind the equator. Its action will evidently be chiefly that of extorsion, while, when the eye is turned strongly in, it will be an elevator, and when the eye is turned out, it will combine torsion with abduction and elevation (Fig. 83).

Exactly what part each muscle plays in the coördinated movements of the eyes we do not know; we can only theorize. The simple movements, such as adduction and convergence, can be occasioned by the action of the interni alone. A combined action of the superior and inferior recti would aid convergence, but we cannot say that they are so used regularly or even in case the internus alone is insufficient. Neither can we say they are not so used.

Abduction of the eye can be accomplished by the externus alone. It would be aided, theoretically, by the combined action of the two obliques, but we have no proof that it is or is not. The more complicated motions are far beyond us as yet and are among the complicated problems of physiology. Still further, the motion of the eye consists not only of an active contraction of one muscle, but a limiting contraction of its opponent or opponents. Otherwise the eyeball would turn as freely as a turnstile and continually overshoot the mark. But all the various movements are dominated in health by the imperious necessity of single binocular vision. The selection of this muscle or combination of muscles, the extent of the contraction of each and their coördination are all so determined by the brain that the two images of the object of regard shall fall on corresponding parts of the two retinæ. A moment's thought will show how in the simplest movements the most delicate picking and choosing of muscles is necessary. If we turn the eyes to some object on the right, we contract the right externus and left internus, but not only must their contraction be exactly equalized to prevent diplopia, but their antagonists, the left externus and right internus, must stop the movement at exactly the proper time by a coördinative action, lest the eyes overshoot entirely the object of regard.

The chief function of the oblique muscles is to keep the vertical planes of the two eyes always parallel by antagonizing the torsion which we have seen is inseparable from the action of the straight muscles in certain positions. It is probable too that in certain positions of the eyes they reinforce the superior and inferior recti and act as elevators and depressors. For instance when both eyes are turned to the right and up, the right superior rectus is a pure elevator and acts more efficiently than the left which is in a position to cause torsion instead of elevation. The left inferior oblique would here act as an elevator and reinforce the superior rectus. In other positions of the eyes there is always an oblique muscle so placed as to assist the straight muscle when it is at a mechanical disadvantage.

The Nerve Supply of the Muscles.—The movements of the eyes are regulated by centres of different rank. In the first place there are centres which govern the action of each individual muscle, the nuclei of the nerves which supply each one, electrical stimulation of which would result in uncoördinated movements of the eyes. These are situated on the floor of the fourth ventricle and have been pretty well localized by experiments on the brains of monkeys. The most anterior one is the nucleus of the *motor oculi,* or third nerve, which consists of several pairs and one unpaired group of ganglion cells and in a physiological sense must be regarded as being composed of a number of nuclei, each of which innervates a separate muscle, though the exact localization in man has not yet been worked out. The fibres from these associated nuclei unite in a common trunk at the base of the brain which passes forward to the orbit and supplies all the ocular muscles except the externus and superior oblique, giving off filaments to the ciliary muscle and iris.

The *trochlear nerve* which supplies the superior oblique has its nucleus right behind that of the third nerve, of which it might almost be regarded as a partial nucleus. The *abducens* which supplies the external rectus has the nucleus still further back on the floor of the fourth ventricle. It will be noted that the muscles which act together have their nerve nuclei together, as for instance convergence is always accompanied automatically by accommodation and contraction of the pupil. In the same way the nucleus of the superior rectus is near that of the inferior oblique which is supposed to assist it in elevating the eye, while the superior oblique and inferior rectus have their nuclei in propinquity.

Presiding over these are centres of higher rank for coördinating the action of the muscles. Their location is unknown. They depend for their stimulation on the visual sensation made by objects on the retina and govern the muscles by acting through the nuclei of the nerves already alluded to. Their function is the preservation of binocular vision. Their action is entirely beyond our control except that we can affect them indirectly by manipulating the object of regard and so changing the visual stimulus.

There is a third set of centres presiding over the ocular movements, namely the volitional ones by which we control the direction of our gaze. These centres also act through the nuclei in the fourth ventricle, but are subject to the second centre in that they cannot cause any conjugate action of the eyes which would result in diplopia. We can turn both eyes at will to the right or left, up or down, or combinations of these conjugate motions by aid of these voluntary centres which are located in the motor area of the cortex. If one eye be blind, or if we are in a dark room, or if we avoid fixing any object, the visual lines may or may not be parallel, but the instant a clear image is formed on both retinæ, the involuntary coördination centres assert themselves in an automatic effort to avoid diplopia.

The actual localization of all these centres has not been worked out, but they exist, since an injury to the motor area may entirely abolish the movement of both eyes to the right or left without paralyzing any ocular muscle. Or one may without any paralysis of his interni lose entirely his power to converge the eyes. Lastly we may have lesions affecting the basal centres which cause paralysis of one or more muscles and which, of course, interfere with both the voluntary and involuntary movements of the eyes.

Binocular single vision is a very important function to the individual. An object seen with one eye singly appears flat, while seen by two eyes from slightly different points of view it gives the impression of depth and solidity. With a single eye judgment of the size of objects depends on the size of their image on the retina. In such a case a small object near by and a large one further off appear to be of the same size. With both eyes functioning our judgment is aided not only by the size of the respective images on the retinæ, but by their distance as estimated from the amount of convergence necessary in fixing each. A one-eyed individual can learn to tell whether a surface is raised or depressed by interpretations of light and shade, and to estimate fairly distance and size.

Binocular single vision occurs when the images of the object of regard fall on identical portions of the retinæ and is converted with binocular double vision whenever one of the two eyes leaves the correct position of fixation. A person who is blind in one eye or who has learned to suppress one image sees singly, but this is not binocular single vision.

We direct a patient to look at a candle flame at a distance with both eyes. If one eye is manifestly turned in or out, binocular vision cannot be present, and he must either be blind in the deviating eye or be suppressing its image or seeing double. If we now cover its fellow, the deviating eye will, unless blind, move so as to bring the image on the macula and the slightest *movement of redress* is evidence not only of sight, but that, if vision is single, it was kept so by suppressing one image. The movement of redress can be distinctly seen in cases where the deviation is too slight to be apparent. There are also cases in which the eyes *appear* to deviate without actually doing so. In these there will be no movement of redress.

As we shall see a little later, if two images are seen, their relative position, distinctness and distance apart are very valuable means of determining the deviation of the visual axis. A similar test near at hand can be made at a distance of ten inches with a pencil and a card, the observer standing directly in front of the patient whose eyes should be in a good light.

Another test of binocular vision is this. If we place over the right eye a prism of 6° base down, the object flame is displaced upward and the patient sees two flames, one above the other. If, however, he sees only one it is because he suppresses the other or is blind.

If a patient whose eyes are convergent looks at a distant candle, he will see two images, one of which is formed—let us suppose—at the macula of the right eye and is distinct and correctly located. The left eye has rotated so that the image falls on the inner half of the retina and, being extramacular, is indistinct and hence called the *false image.* But the patient long ago learned that objects whose images fall on the right half of either retina, are actually on the left side of the body; consequently, while the true image seems straight in front, the false one seems to be farther to the left. If the left eye was unduly divergent, the image would fall on the temporal half and seem to be to the right of the real image. If the eye were depressed, the false image would be formed on the lower half and would seem to be above the true image. When the false image is situated on the same side of the body as the eye to which it belongs, the diplopia is said to be *homonymous* and always indicates convergence of the visual lines. When it is on the opposite side it is said to be *crossed,* invariably indicating divergence. When one image is higher than the other, the diplopia is vertical.

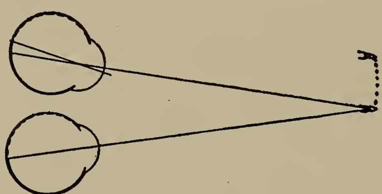


FIG. 84.

Vertical diplopias are further distinguished by noting the eye which has the lower image. If the image formed in the right eye is lower, it is *right diplopia,* and *vice versâ.* We can discover to which eye each image corresponds by covering one and having the patient tell which image disappears, or by placing a red glass before one eye so that the image formed in the eye shall be red.

CHAPTER XI.

NORMAL MOTILITY.

In examining the motility of the eyes there are three conditions to be investigated: first, the relation of the visual axes to each other, when the muscles are completely relaxed—the *position of rest;* second, the ability to keep these axes so related to each other in the ordinary movements of the eyes that binocular single vision shall always be present—the *fusion power;* and third, the *voluntary*

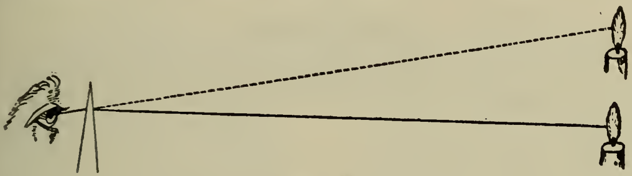


Fig. 85.

power to move the eyes as a pair in various directions—the power of rotation. Each one of these requires its own special tests and has its own special significance under various conditions.

The Position of Rest.—We remember it was the chief function of the coördinating centres controlling the fusion power to keep the optic axes parallel for distant objects and to avoid diplopia, and we can only determine whether that is their natural position or not by abolishing for the time being the power of fusion, which may be done in several ways.

Prism Test.—We use as our test object the flame of a candle or some distinct round object of equal size placed at a distance of twenty feet (Fig. 85). If we now place over the patient's right eye a prism of 5 △ base down, the image of the flame is thrown below the macula of that eye and the candle appears displaced upward. If the prism were a weaker one, the eye would, under stimulation of fusion, rotate in such a way as to bring the macula to the new site of the image, but if the prism is strong enough the fusion power is overcome and the patient sees two flames. If one flame is directly above the other, it is evident that the vertical planes of the eyes are still parallel. If the eyes were turned in or out, the candles would not only be dis-

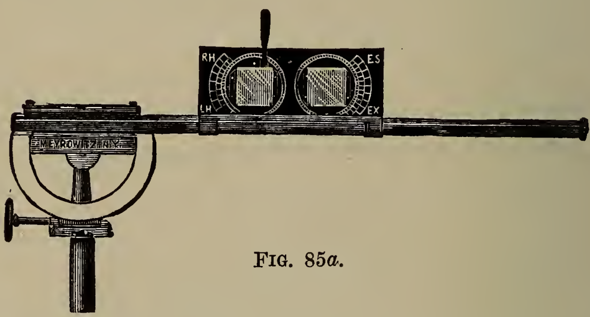


FIG. 85*a*.

placed vertically, but also laterally. Removing the first, we now take a prism of 8 △ or 10 △, or one strong enough to produce diplopia and place it over the eye with the base in, the flame is displaced toward the apex, and if the patient sees two flames side by side, the axes must both be in the horizontal plane, since, if the eyes deviated vertically, one candle would be higher than the other.

A convenient application of this test is made with the Stevens phorometer (Fig. 85*a*) consisting essentially of two 5 △ prisms, one before each eye, and rotating in opposite directions, giving the same displacement as a 10 △ prism. With the prisms rotated base in, in such a way that two lights appear exactly on the same level the amount of hyperphoria is indicated by a pointer. With the prisms rotated so that one light appears on a line above the other the amount of esophoria or exophoria is similarly indicated. This is a very delicate test of the relative position of the visual lines to each other, and there are a number of tests based on similar ideas. If, for instance, we place a *red glass* over one eye, it reduces the illumination and causes the flame to appear red. The tendency to fuse a red flame and a white one is much less than two white ones, and if

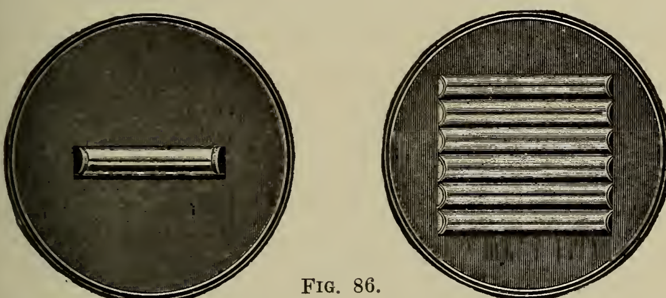


FIG. 86.

the patient sees them side by side, the optic axes must be deviating laterally, while if one is above the other, they must be deviating vertically. The fusion power is, however, not entirely abolished, and the test is nothing like as delicate as the preceding. The advantage from a practical point of view is that the patient can describe the relation of the images more accurately by their color, and that when diplopia is present the lateral and vertical deviations are shown at the same time. Absence of diplopia does not show a normal balance.

Maddox Rod (Fig. 86) consists of a glass rod or series of rods closely touching each other so as to produce the optical effect of a very powerful convex cylinder. This is placed in a trial frame before the right eye when the flame of the candle at once appears as a long, narrow band of light at right angles to the axis of the rods. There is no tendency to fuse two images as dissimilar as a candle flame and a band of light, hence each eye assumes the position of rest. When the band of light is vertical, it should pass directly through the flame as seen by the other eye, and any separation shows a lateral deviation inward or outward. The rod is now turned in the trial frame till the band is horizontal, when it should still pass through the flame, any separation in this position showing that in the position of

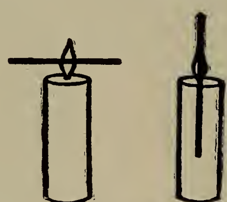


FIG. 86*a*.

rest one eye points higher than the other. This is a very good test. It is to be noted, however, that in the great majority of patients, when the band is vertical the test shows a slight convergence of the optic axes which other tests often do not show (Fig. 86*a*).

Duane's Test.—Using a distant candle and placing ourselves in such a position that we can see both eyes distinctly we interpose a card or screen, first in front of one eye and then the other. The eye behind the screen, no longer being stimulated by the image of the candle flame, at once assumes the position of rest. If the visual lines in this position are divergent we can see the eye turn out behind the screen and if we then withdraw the card the eye, in again fixing the flame, makes a distinct movement of redress inward. If the eye deviates in behind the screen, with a movement of redress outward when the card is removed, we know that the position of rest must be one of convergence and the same reasoning holds good of vertical deviations, the movements of deviation and redress being up and down; while if no motion of the eye can be detected either behind the card or when the card is withdrawn, the visual lines are practically parallel and the position of rest nearly normal. If the eyes deviate outward behind the card we can, by placing a suitable prism base in over the eye, so change the direction of the rays from the flame that on the withdrawal of the card they fall on the macula without the necessity of any movement of redress; while if the prism is too strong the movement will be reversed, the eye turning outward instead of inward when the card is withdrawn. Duane, who suggested this test, considers that if a distinct reversal of the movement of redress occurs with a 10° prism there will be no perceptible movement in either direction with a 7°, 8° or 9°, and that the 8° is therefore very nearly the mean deviation.

Position of the Vertical Planes.—Using the candle flame as an object as before, we place before the one eye a Maddox rod with its axis carefully horizontal and over the other a similar rod with axis vertical. From the first the eye gets the impression of a vertical band of light, while the other eye sees a horizontal one. If the vertical planes of the two eyes are exactly parallel in the position of rest, these bands should intersect at right angles. If the vertical planes are not parallel, the angles of intersection will not be right angles, and one eye or both must evidently have been rotated wheel-fashion, either intorsion or extorsion.

Double Prism Test.—The Maddox prism is composed of two prisms in a trial ring, so arranged that their bases touch, their line of junction passing exactly through the centre of the ring. If this is placed before one eye, so that this line passes horizontally in front of the centre of the pupil, it will cause a monocular diplopia, and the horizontal line used as a test object will appear as two parallel lines. If, now, the other eye be uncovered, it sees a single line which, if no torsion of either eye has taken place, should be between and parallel to the other two lines.

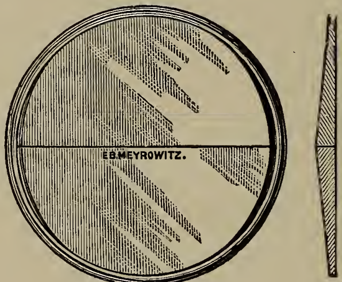


FIG. 87.

Convergence and Accommodation—Metre Angle.—If, in the position of rest, the optic axes are parallel, a point of light infinitely distant will be seen singly without either convergence or divergence. If, now, this point be approached to a distance of one metre, the eyes move through a definite angle known as a metre angle—(M. A.). Evidently if the object be two metres distant, the angle will be only .5 M. A., while if the object is still seen singly at half a metre, the convergence amounts to 2 M. A.

Attention has before been called to the fact that there is a normal relation between convergence and accommodation. In the previous test, for instance, in fixing an object at a metre, the patient not only converges 1 M. A., but if his refraction is normal, accommodates 1 D.; at a half metre 2 M. A. and 2 D., etc. This intimate relationship is also indicated by the close association of the centres for convergence and accommodation. So close is this relationship that, if, owing to refractive conditions, accommodation is increased or reduced, the tendency to converge undergoes a corresponding change which has to be compensated for in some way. It follows that just as in the primary position of the eyes there should be single vision of distant objects without the stimulation of fusion, so for near objects there is a state of equilibrium between accom-

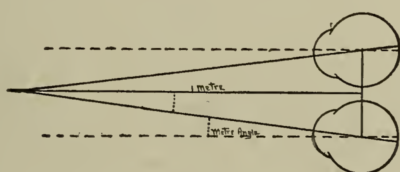


FIG. 88.

modation and convergence, so that the optic axes automatically fix the same point without the necessity of fusion stimulation. To discover whether the eyes are in a position of equilibrium for near work, the following tests are useful.

Cover Test or Screen Test.—Having the patient fix the point of a pencil or other small object at a distance of eighteen inches, we interpose before one eye a card. If the balance between accommodation and convergence is perfect, the covered eye automatically maintains its exact position. If convergence is in excess the covered eye having nothing to fix, turns in, while if it is insufficient it turns out, and if these deviations are extreme they are apparent when the observer looks behind the screen, but it is often too slight to be made out in this way. If, however, we closely watch the screened eye and quietly withdraw the screen, it will at once fix the object by a movement of redress. If it moves in, it must have been divergent behind the screen, while if it moves outward the convergence must have been in excess of the accommodation.

Graefe Equilibrium Test.—If we place before the right eye a prism of 5 △, base up, and have the patient look at a black point on a card held at the ordinary reading distance, the image seen by the right eye will be displaced and ap-

FIG. 88*a*.

pear lower down than its fellow. But if both eyes accommodate for this distance, they should also automatically converge for the same distance and one dot should be exactly above the other, and any lateral deviation shows an abnormal proportion which must be rectified by stimulation of the fusion power. This can be measured by the prism required to bring the dots into line, or a card used showing on its printed scale the prism equivalent of the displacement.

FUSION POWER AND ITS MEASUREMENT.—It is evident that diplopia for distance would occur in all eyes whose position of rest was not with axes parallel. Diplopia at the near point would regularly occur whenever the eyes were not in a position of equilibrium at that point. In other words, every conceivable lack of balance of the extrinsic ocular muscles and every refractive error would produce more or less diplopia, unless nature had provided some means of compensating for her defects. This compensation is provided by the fusion power which is presumably in abeyance in normally balanced eyes, but which, in the presence of diplopia, imparts an extra stimulation to the muscles necessary to correct it.

While the determination of the position of rest and equilibrium depends on our power to abolish fusion, the

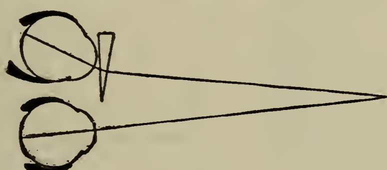


FIG. 89.

coming series of tests of the compensatory power of the eye depends on its highest stimulation. No matter how good the condition of the muscles, fusion will not occur if the retinal stimulation be so slight that the image in one eye can be easily suppressed. To bring out the utmost fusion power the vision in each eye must be made as perfect as possible.

Convergence Tests.—The patient regards the flame of a candle at a distance of twenty feet and a prism of 5 △ is placed before the left eye with the base out. The image of the flame, instead of falling on the macula, is deflected toward the base of the prism and falls on the outer half of the retina causing a cross diplopia. Under the stimulus of fusion the macula is immediately rotated outward to the new site of the image by a contraction of the internal rectus and the images are focussed and the diplopia vanishes. We now take stronger and stronger prisms in turn, each one increasing the distance of the image from the macula and consequently the contraction of the internus necessary to secure single vision. Finally we reach one so strong that the internus has not the required strength to overcome it and the diplopia persists. The strongest prism which has been successfully overcome measures the ability to converge that eye.

The value of the test depends largely on the care and skill with which it is made. Since it depends on the utmost stimulation of the fusion power, the value is impaired by anything which reduces the clearness of vision in either eye. Consequently, it is a mistake to follow the common plan of determining the presence or absence of diplopia with the red glass and then, without removing this, to measure the prism convergence. The image seen through the red glass is not only much fainter, but of a different color, and only a slight effort is made to fuse images so dissimilar. Plenty of time should be allowed before deciding that the limit of strength has been reached, for very frequently after stimulation by a few weak prisms the eyes will overcome a prism diplopia which would have been hopeless at first. Many consider the ability to overcome prisms more of a knack than a measure of actual strength.

This leads to another disadvantage of the test as ordinarily made. The sharper the vision, the greater the fusion tendency. Consequently, weak prisms which displace the image but a short distance from the macula are readily overcome, but when strong ones are reached which throw the image to the periphery of the retina, not only are the images very far apart, but one of them is very indistinct and the stimulation of fusion is very much reduced. To overcome this defect, the

Rotary Prisms have been devised, consisting of two or more prisms rotating in opposite directions by a screw in a common frame and thus furnishing a prism which can be varied from 0 to 30 △. With such a prism, gradually increasing in strength without being taken from the eye, the image is always just beyond the macula where the fusion power is strongest and the eye thus stimulated to its extreme power. Great care should be taken in estimating the convergence with prisms, that the patient does not twist or tilt the head and that the prism has its axis so that the images are exactly horizontal, since in this position the eyes will overcome much stronger prisms than when one is higher up than the other.

FIG. 90.

If now the other eye be tested in the same manner, we shall ordinarily find that the strength of its internus is practically the same. We might at first sight assume that if each eye can overcome a prism of a certain strength, the two together ought to overcome the combined prisms. It will be found that the two together can accomplish little more than either singly. While the internus of the eye behind the prism is in a state of contraction great enough to move the eye, the internus of the fellow eye is almost as tense to preserve its own position. Differences in the prism power of the two interni are ordinarily due to differences in the amount of fusion stimulation. If one eye has reduced vision it may hold its position very well while the image is formed at its macula and so allow the better eye to overcome a strong prism. When, however, the prism is transferred to the worse eye and the image thrown away from the macula, the retinal stimulation is so feeble that the true prism power is not shown and very often the image, if faint, is suppressed altogether.

Divergence Tests.—We place over one eye a weak prism, say 2 △, with its base in, carefully adjusting its axis horizontally. The rays from the candle are so deflected by the prism that they fall to the inner side of the macula, and being projected in the direction of the apex of the prism, cause a homonymous diplopia. Under the fusion stimulus, the external rectus contracts so as to rotate the macula inward to the site of the image and abolish the diplopia. We then gradually increase the strength of the prism and the strongest one which the externus can overcome is the measure of the divergence power. If we proceed to apply the same test at once to the other eye, we shall probably find that its power is apparently somewhat less, owing to this fact: the two externi work together in divergence, the one behind the prism being active and the other passive, so that the second is already tired before being measured. We have seen that the convergence power seems to increase through the exercise of testing, because convergence is an act to be actually performed through powerful muscles. Divergence is not called for in normal eyes and is performed through relatively weak muscles, and prism exercise does not increase the divergence power materially.

Sursumvergence.—If we place before one eye a weak prism, say 2 △, with the base down, the rays from the candle fall below the macula and the image in that eye being projected appears directly over that of the other a vertical diplopia. This is corrected by the superior rectus which, by contracting moves the macula down to the other site of the image. Gradually increasing the strength of the prism, the strongest which can be overcome is the measure of the strength of the superior rectus.

Deorsumvergence.—The strongest prism, base up, which can be overcome is in a like manner the measure of the power of the inferior rectus.

In these last tests it must not be forgotten that, while the superior of one eye is actively contracting to overcome a prism, the inferior rectus of the other is nearly as tense to prevent its also moving upward, so that tests of the vertically acting muscles involve both eyes.

Torsion.—It must also be borne in mind that the oblique muscles may take part in the elevating and depressing of the eyes and, if so, their power is included in these tests. Their chief function, however, is in maintaining a parallel position of the vertical planes of the two eyes. We have already seen how to ascertain whether they are parallel in the position of rest. We now place before each eye a Maddox rod, axis horizontal, which causes the patient to see two vertical bands of light which, being exactly alike, are immediately fused. If now we rotate one rod slightly, the band ceases to be vertical, but under the fusion stimulus the eye rotates wheel-fashion, so that the band shall still fall on the vertical plane of the retina. When the rod is rotated further, beyond the power of the oblique, the patient sees two bands crossing each other at an acute angle. The number of degrees through which the rod can be rotated without producing two bands, is a rough measure of the ability of the oblique muscles to keep the vertical planes parallel. It is not to be forgotten that the oblique muscles work in pairs and we have no means of estimating each separately. Stevens has devised a very ingenious instrument, the *Clinoscope,* for measuring and

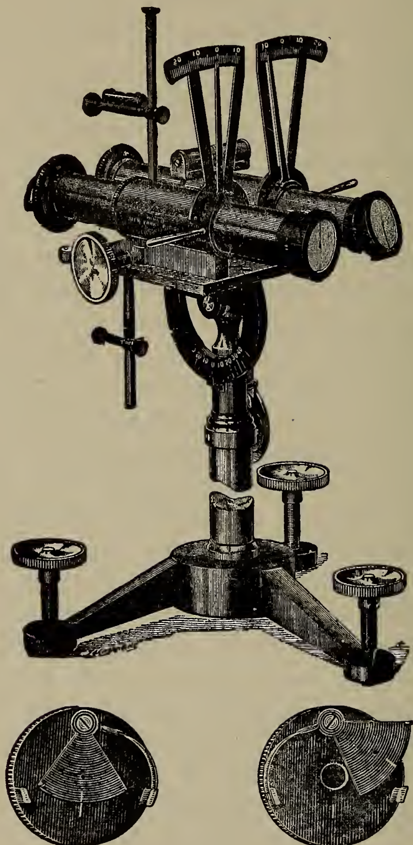


Fig. 91.

recording the torsion powers of the obliques. The instrument consists of two cylindrical tubes mounted on a brass platform, which holds them firmly in the same horizontal plane. The attachment to the platform permits the tubes to be adjusted in parallelism, in convergence, or in divergence in the plane of the platform. The platform is attached by a movable joint to the upright standard, so that the instrument may be given any desired dip, and a scale and pointer indicate the dip with respect to the horizon. The tubes are caused to rotate upon their longitudinal axes by means of thumb screws, as seen in the figure, and the pointer and scale above the tubes mark the rotation with accuracy. At the proximal end of each tube is a clip, in which the observer may insert a glass for the correction of refraction. At the distal end is another clip and provision for maintaining precise position of the diagrams to be used in the investigation. These diagrams are haloscopic figures, calculated to aid in the various experiments which may be made. These may be varied according to the wish of the investigator. For testing the ability of the eyes to rotate upon the antero-posterior axis (torsion), a straight line running across each disc is the most useful figure. The lines may be placed vertically or horizontally. It will be found that the rotating ability is much greater when the lines are vertical.

The clinoscope is an instrument of much value in determining the declination of the meridians in paralysis of the eye muscles, in anomalous adjustments of the eyes in respect to the horizontal visual plane and in determining the power of torsion or increasing the torsional ability by exercise.

Relation of Fusion Powers.—So far nothing has been said to indicate the amount of fusion power which the normal eye should have, because there is no fixed scale to which all agree. Fusion depends first on retinal sensation; second, on the amount of reflex nerve stimulation, and, lastly, on the size and strength of the muscles. In all these particulars individuals vary widely. But if there is no exact standard of measurement which can be applied to different individuals, there is a fairly definite proportion which subsists between the fusion power of different muscles in the same individual, any marked departure from which is pathological.

Convergence, for instance, is a power which is continually used by all of us and yet, while the average individual can overcome at the first trial a prism of 15 △ to 20 △, there are many who can with difficulty overcome 10 △ and yet have no symptoms, while occasionally another can develop 40 or 50 △. Divergence is not so useful and is always weak, varying from 2 △ up to 12 △, but if the same individual has a convergence of 40 △ and a divergence of only 2 △, it is very apt to occasion symptoms which we shall take up later. Ordinarily, divergence should be about 5 △ or 6 △ and convergence between 15 △ and 20 △, or in this proportion. In other words, convergence should be from three to four times as strong as divergence.

The ability of the inferior is always greater than the superior, the latter averaging 2 △ to 4 △ and the former 3 △ to 6 △. The proportion between superior and inferior is not so important, so long as it is the same in both eyes, since as long as the visual lines are in the same horizontal plane, that plane can be raised or lowered by tipping the head up or down without moving the eyes in the orbits.

If the power to overcome prisms is weak but proportionate, it may be because of poor vision, retinal anesthesia or failure of the fusion centres. If it is very great and proportionate and well maintained, it indicates strong stimulation and centres and healthy muscles. If not maintained, it shows innervation in excess of muscular power. If not proportionate, since the fusion impulse is equal for all, it indicates an abnormality of muscular balance.

We have studied the fusion power which is a matter chiefly of innervation and not of actual muscular power. For instance, in converging the right eye to overcome a prism of 40 △, the internus only moves the cornea through an arc of 20° of a circle, and in diverging 5° the cornea only moves 2.5°, while it is evident that in turning both eyes to the left, the internus moves the cornea many degrees farther, and in turning both eyes to the right, the externus has almost as great a power. Evidently there must be a motility of the eyes we have not measured as yet, and that is the muscular power when under the control of the will.

Voluntary Motions of the Eye.—These consist of movements of both eyes together to one side or the other or up or down or combinations of these movements. When gazing at objects directly in front, the fusion instinct keeps the axes parallel and so coördinates the motion of the two eyes, but in extreme rotations to the right or left or up or down, a screen is interposed over one eye in the shape of the nose or cheek or brow so that binocular vision is impossible and the extreme rotation occurs without the usual limitation interposed by the necessity of binocular vision. Since the rotation of the eye in these conjugate movements are much greater than in any other, since they can be made of each eye singly without regard to the other and since they are voluntary, their movement is the truest test of the individual *muscles* of the eyeballs.

Linear Measurement.—This is a very rough test which will detect only gross variations from the normal and can be applied only to the inward and outward rotations. Having the patient place his eyes in the primary position, we direct him to look to the right as far as he can and then to the left, noting whether the margin of the cornea passes or falls short of the respective canthi. Or a mark can be placed on the lower lid showing the position of each margin of the cornea. But such tests are absolutely unreliable where accuracy is desired.

Measurement by the Perimeter.—We place the patient before the instrument with the eye to be tested carefully adjusted to the sight notch. As our test object we take a small card with several small dots at the centre, and beginning at the centre of the arc, slowly move it outward, the patient being directed to follow with the eye but not with the head. After the card has reached 45° more or less, the patient has reached the limit of ability to move the eye, and as he can no longer keep the macula on the dots he ceases to see them clearly and separately. Making a note of the reading on the arc opposite the centre of the card, we proceed to measure the inward rotation in the same way, and then placing the arc in a vertical position we measure in like way the upward and downward rotation. It often happens, however, that one has to measure the excursions of eyes which have poor sight either intrinsically or without glasses, where the dot test is unavailable, and there is always the difficulty of getting the patient to distinguish between mere seeing and the distinct vision which indicates the position of the macula. We can make the test more objective by using a candle or small electric light instead of the card. If the patient be directed to fix the light at the centre of the arc, the observer, whose eyes should be directly behind the light, will see a distinct reflection in the centre of the patient's pupil. Directing the patient to follow, and keeping his own eye in line, the observer moves the light along the arc till the reflection ceases to be seen in the centre of the pupil, which indicates that the eye has reached the limit of its ability to follow. The mark on the arc opposite the light indicates the ability

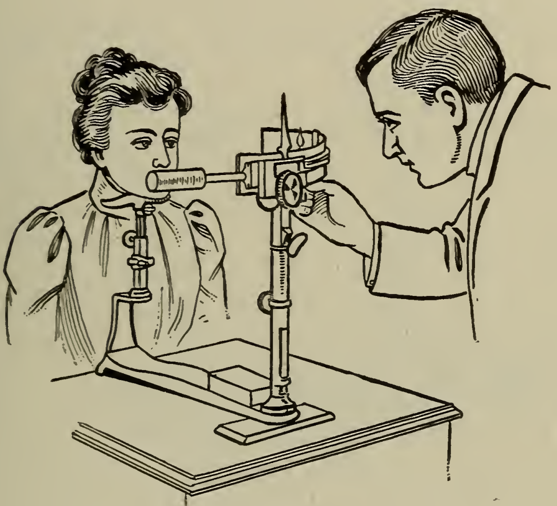


FIG. 92.

of the eye to rotate in that direction. In this way we can get a fairly accurate estimate of the contraction of each muscle, the outward rotation being caused by the externus alone averaging about 45°, the inward by the internus alone averaging a little higher, about 50°. The downward rotation is caused *theoretically* by the combined action of the inferior rectus and superior oblique and averages 40°. If we wish the action of the inferior alone, we can adjust the head so that when the eye fixes the centre of the arc, it is turned slightly outward in such a position that the oblique loses its depressing power and effects only torsion. The upward rotation caused by the superior rectus and inferior obliques measures about 30°, partly because these muscles are weaker and partly because the position of rest of the eye is slightly below the horizontal. By turning the eye slightly outward, we can nullify the elevating action of the oblique and get the power of the superior alone if we wish.

There are some disadvantages about the perimeter method, chief of which is this, that in a patient with a prominent nose the entire inward rotation cannot be measured, since the bridge of the nose prevents alike the patient seeing the light and the observer, keeping in line with the light, from seeing the cornea. With a deep orbit or prominent brow and cheek the upward and downward rotations are obtained with difficulty. The perimeter also fails of any method of placing and keeping the patient's head in a symmetrical position. Evidently, if the patient's head is tilted forward, he will have a much reduced ability to elevate his eyes and a corresponding increase in his downward rotation. If his head be turned slightly to the right, his eyes will be turned toward the left, and he will have a correspondingly diminished rotation toward the left and increased toward the right. The tendency too is for the patient in his eagerness to follow the light to turn his head when his eyes have reached their limit. Therefore, the perimeter, while in theory an exact instrument, is in practice liable to cause many errors which can be avoided only by experience and skill.

The Tropometer of Stevens retains all the advantages of the perimeter and does away with most of its disadvantages. It provides means for ascertaining that the head is erect and neither turned to the right nor left and that the eyes are on the same level; in this position the head is secured by gripping a bar of wood with the teeth and by the pressure of clamps on the forehead and occiput. The movements of the eye are observed through a telescope,

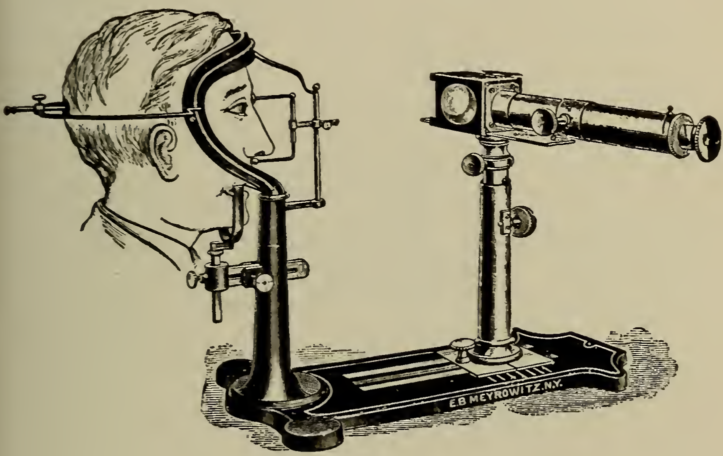


FIG. 93.

the corneal margin traveling along a scale corresponding to the degrees on the perimeter.

With this instrument it is possible to measure not only the rotation of the eye up and down, in and out, but by adjusting the head so that the oblique muscles lose their elevating and depressing power, we can estimate directly the power of the superior and inferior recti.

We have seen that in the ideal patient the two eyes should not only be absolutely emmetropic, but

1. In the position of rest their visual lines should be parallel, and their vertical planes as well;

2. That the relation between convergence and accommodation should be so perfect that in near work the visual lines should impinge on the same point without the intervention of any fusion impulse;

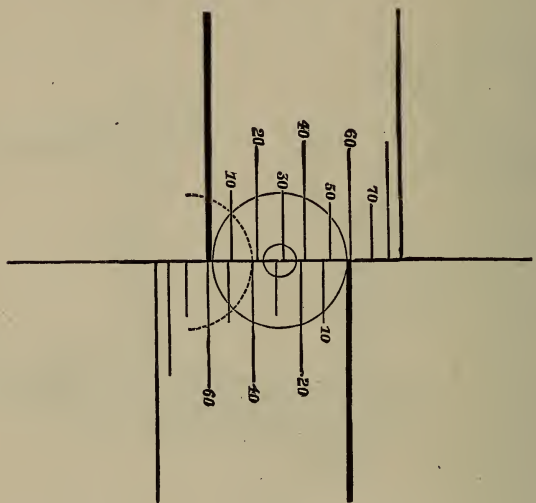


FIG. 93*a*.

3. That in conjoined movements to the right and left or up or down the eyes shall maintain single vision without the intervention of the fusion power.

4. That where this ideal condition is not present, a working balance is maintained by the fusion power which depends on

a. Retinal stimulation, which can be assumed as normal when the visual acuity of each eye is normal;

b. Proper innervation, which is wanting when with good vision in each eye the patient cannot be made conscious of diplopia by prisms and is normal when the proportion of prism power is normal;

c. Muscular power—which is normal when the prism proportion is normal and the voluntary rotations of the eyeball normal in extent.

CHAPTER XII.

HETEROPHORIA.

Orthophoria.—The term *orthophoria* is used to denote an absolutely normal balance of the extrinsic muscles, just as the term emmetropia denotes a normal refractive condition. They are equally rare.

Heterophoria.—The term *heterophoria* includes all those conditions in which there is a demonstrable *tendency* to depart from the normal balance but which nature is able to compensate for, while the term *heterotropia* includes the conditions in which nature has been unequal to the task and an *actual* turning or squint has occurred.

The subdivisions of these terms at first sight appear complicated, but on closer study are simple enough, indicating only the direction of the turning or tendency to turn. For instance:—

Esophoria signifies inward tendency.	Esotropia signifies inward turning.
Exophoria signifies outward tendency.	Exotropia signifies outward turning.
Hyperphoria signifies upward tendency.	Hypertropia signifies upward turning.
Hypophoria signifies downward tendency.	Hypotropia signifies downward turning.
Cyclophoria signifies tendency to torsion.	Cyclotropia signifies actual torsion.

Combinations are describable in similar terms. A tendency of the right eye up and inward is a right hyperesophoria, of the left eye down and out a left hypoexophoria, etc. Tendencies of both eyes together are denoted by the terms which follow:—

Anaphoria signifies an upward tendency.
Kataphoria signifies a downward tendency.
Dextrophoria signifies a right tendency.
Laevophoria signifies a left tendency.

The Cause of Heterophorias is a matter of dispute, some authorities claiming that they are invariably congenital anatomical defects, and others that they develop as the result of uncorrected refractive errors. Probably the truth lies somewhere between the two extreme positions. The human body is never absolutely symmetrical and it is extremely improbable that any pair of eyes were ever exactly alike either in their refraction or their muscles. In this sense heterophorias are often congenital and primary. Occasionally we see also certain gross muscular defects that seem to be present in several generations of the same family and go with certain cranial types, but as a rule we have no evidence that children are often born with any but the slight defects of muscle balance which are easily and perfectly compensated for by the fusion powers. At present we have no means of estimating the muscle balance in young infants which entitles us to be dogmatic on either side. But granted a slight congenital imbalance, compensation through the fusion sense may be prevented by poor vision or defective centres, and the imbalance may increase indefinitely till it becomes an actual squint. Even if the balance was perfect at birth, refractive errors may gradually destroy it. For instance, hyperopia and astigmatism, which cause undue accommodation, at the same time cause undue convergence and thus produce an esophoria which is at first purely functional, but as the interni hypertrophy from overstimulation becomes anatomical. If this occurs after maturity, the hypertrophy is often a temporary one which gradually disappears when the cause is removed, but when it occurs in the plastic period of childhood, it is much more apt to result in a permanent increase in bulk and strength. If the muscle is stimulated beyond its powers of response, it finally atrophies and a divergence results. In this way can we best explain the divergence so common in the myope with his very close far point.

SYMPTOMS—These depend on the kind of error present as well as the degree, and vary widely. In general they may be said to fall into three classes, defective vision, pain of greater or less degree, and reflex symptoms. *Defective vision* may be present even though each eye has a normal visual acuity, since even when compensation is very good the brain gets the impression of two objects very nearly but not quite fused, and vision may be considerably worse with both eyes together than with either singly. When compensation is considerably impaired, the diplopia becomes more and more persistent, till the brain finally makes choice of one image as more satisfactory and suppresses the other entirely. Visual acuity may not suffer in either eye, but vision being no longer binocular, everything is seen in the flat, the judgments of depth and distance being regularly more or less defective. This is a tremendous disadvantage in many occupations. Patients gradually get accustomed to these visual defects and are not conscious of the handicap, but it is very different with the second set of symptoms—*pains*.

These are more often present when compensation is maintained only by excessive effort. Such patients commonly have good visual acuity in each eye and do not take kindly to diplopia, so the fusion centres transmit a very strong impulse to the extrinsic muscles to restore the balance. If the patient's general muscular condition is bad as the result of poor nutrition or disease, the eye muscles may respond, but soon tire, and continuous stimulation causes pain. In a minority of cases the muscles gradually strengthen from the increased innervation and the pains disappear, compensation being fully restored. In many others the conditions remain unchanged for a long time, the eyes being fully competent for short periods of work, but regularly becoming painful when overused. In another class where the muscular powers are weaker or the stimulation less, compensation breaks down completely with diplopia and suppression of one image, but with a great diminution of the amount of pain.

The character of the subjective symptoms in refractive errors and muscular imbalance is so very similar that it is almost impossible to differentiate from these alone in many cases. In muscular asthenopia, however, in addition to becoming tired easily, the patient often complains that letters seem to run together or to "jump" while he looks at them, or that he sees double for an instant, or he can "feel his eyes turn" involuntarily in their sockets. Like accommodative asthenopia, there are pains in the eyes and frontal headache, neuralgia, etc., but the characteristic pain in my experience is an occipital pain. These pains are sometimes present only during use of the eyes. At other times they persist for hours afterward and, in some cases, at irregular intervals after days or weeks of overstimulation an explosion occurs lasting a day or two in the form of a migraine.

In other cases there are other *reflex symptoms* such as dizziness, nausea, fainting, indigestion, insomnia and pains in other portions of the body which sometimes simulate organic diseases.

The possibility of heterophoria as a factor in chorea, epilepsy, migraine, neurasthenia and other diseases which may be primarily due to unstable nervous equilibrium, is not to be forgotten. It is a notable fact that when the fusion compensation fails so completely that one image is entirely suppressed or the diplopia is so great as to be overlooked, the symptoms often cease entirely.

The Treatment of Heterophoria depends on a careful study of each individual case, but it can not be too strongly emphasized that in the great majority of cases the subjective symptoms disappear after a full correction of the *refraction* under atropin.

In many cases we shall see that if the visual acuity in each eye be made normal, the fusion impulse alone will be sufficient to restore compensation.

Many cases of esophoria result from overstimulation of the centres for convergence and accommodation made necessary by hyperopia and astigmatism, and disappear entirely when glasses abolish the need of accommodation. Cases of exophoria are sometimes due to the abnormal relaxation of accommodation and convergence which secures the best distant vision in myopia. Likewise the correction of myopia, by increasing the far point, may diminish the amount of convergence necessary for near vision. In every case the refraction should be carefully estimated under atropin and, as a rule, fully corrected. The advantages of slight overcorrection of hyperopia in a few cases of esophoria at the near point, with the idea of still further reducing convergence, and of slight overcorrection of myopia in exophoria with the idea of increasing the convergence stimulation and at the same time lessening the convergence necessity by removing the near point, should not be forgotten.

Education of Fusion Impulse.—In a few cases, with perfect visual acuity in each eye, we can with difficulty make the patient conscious of diplopia and his fusion power is out of all proportion to his muscular power as revealed by the tropometer. This can be due only to defective fusion centres. In such cases, if we can once get the patient to be conscious of a diplopia, we can train him to overcome it and gradually increase his fusion powers. For this purpose the stereoscope or amblyoscope are very useful. This is not to be done thoughtlessly, for if restoration of binocular vision is to result in serious asthenopia, the patient is much better off without it.

Improvement of Muscular Power.—In cases where the difficulty seems to be a general muscular weakness due to ill nutrition or disease, as evidenced by low but proportional prism power and nearly normal rotatory powers, much good can be done by general tonic treatment with rest from overwork. Especially is this true of muscular asthenopia developing after confinement or long illness in which a restoration to normal bodily condition often sees the disappearance of all asthenopic symptoms.

Prism Exercise.—Where the tests point to a weakness of a pair of muscles as in deficiency of convergence powers, prism exercises have an undoubted value. The patient fixes a candle flame at a distance of twenty feet, having before one eye a rotary prism, base out; the strength of this is gradually increased till diplopia is produced, after which the strength is gradually decreased to the minimum and after a moment's rest the process is repeated. A few moment's exercise of each internus in this way several times a week, carried to the point of fatigue but never beyond, will often cause a tremendous increase in the convergence power from 7 or 8 △ to 30 △, but if the exercise is regularly carried beyond the physiological limit, it is harmful. In some cases the improvement persists, while in others it gradually disappears.

If the asthenopia is due simply to weak interni, the externi being average according to the prisms and tropometer, the improvement is likely to be permanent. But if the poor convergence is due to overacting externi, prism exercises are of doubtful value. Exercise of the other straight muscles is rarely beneficial. Divergence, whether vertical or horizontal, is, except within very narrow limits, not a physiological function, and the externi, the superior and inferior, do not increase their power notably through exercise.

Prisms for Constant Use are often prescribed, being so placed as to help the weak muscles and counteract the strong. For instance, in exophoria we find the prism which, base in, will produce orthophoria for distance and prescribe a quarter of it, base in, before each eye. While this is very successful in some cases, the tendency[1] in others

---

[1] We sometimes take advantage of this tendency when we prescribe for constant use weak prisms with the *apex over the weak muscle*, which gradually becomes strong from the exercise of overcoming them. This plan is effective only in patients who have a strong fusion impulse, and the prism selected must be weak enough to be easily overcome. We can accomplish the same effect by decentering the patient's refraction lenses. For instance, a convex lens so placed that the visual line passes to the nasal side of its optical centre will have the effect of a prism base out, and the reverse will be the case if the lens is concave. The amount of prismatic action depends on the strength of the lens and the amount of decentering, the rule being that every centimeter of displacement causes as many prism dioptres as there are dioptres in that meridian of the lens. Thus a + 1 sphere or cylinder axis 90 decentered one centimeter outward is equivalent to adding a 1 prism dioptre lens base out.

is for the externus to increase slightly from constant exercise in overcoming the prism while the internus decreases in proportion to the amount of work of which it is relieved. This effect is still more marked when the prisms are prescribed, base out, in esophoria. Prisms for permanent use are very beneficial in vertical deviations, since, when the images are brought on the same level, they require much less effort to secure fusion, and when prescribed base up or down, the effect secured is commonly an unchanging one.

Operative Measures should only be adopted after careful consideration and study of each case. They produce an effect only on individual muscles and have slight value in cases where heterophoria is the result of poor vision or reduced innervation. They are most useful where the tropometer shows an actual increase or decrease in the power of one muscle or pair of muscles as compared with its opponent. Three operations are at our disposal:

Tenotomy, partial or complete, to weaken a strong muscle; shortening, to strengthen a weak muscle; resection, to strengthen a weak muscle.

Partial tenotomy is intended to equalize muscular balance by weakening the power of the stronger. Theoretically it should only be employed where prism tests and especially tropometer tests show that the muscle operated on is not only out of proportion to its antagonist, but also possesses more actual power to turn the eye than it should have. For instance a rotation of 45° in and an outward of 35°, would certainly not call for tenotomy of any sort, since it would still further reduce the power of an internus that is already hardly up to the standard. On the other hand, an inward rotation of 70° and outward of 45° would certainly call for a reduction of the power of the internus rather than an increase of the externus and the tenotomy might be advisable. At the same time it must not be forgotten that any operation which increases or diminishes the power of one muscle has a corresponding effect on its antagonist. For this reason partial tenotomy has been clinically beneficial in many cases in which it was not theoretically indicated. Its advantages are that it is a safe operation entailing a minimum of inconvenience to the patient, and that its effect can be tested from time to time

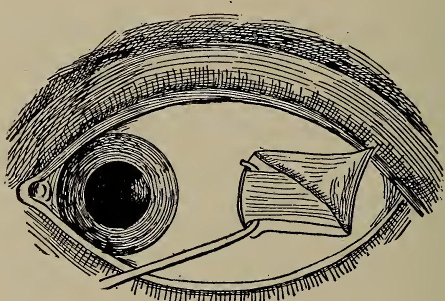


Fig. 94.

during the operation, if desired. Its disadvantage is that in many cases the process of healing and cicatricial contraction destroys the effect of the operation, and that, if overdone, its rectification is not so simple. Under cocaine anesthesia and with or without a speculum the patient is directed to rotate his eye so as to bring the insertion of the muscle selected into the field. With a mouse-toothed forceps the conjunctiva, capsule of tenon, and tendon of the muscle are picked up together just back of the insertion and nicked with scissors if only a slight effect is desired, the line of incision being at right angles to the course of the muscle. The idea is to cut through the central fibre of the tendon which retracts, thus lengthening the muscle in proportion to the length of the incision. If it is desired to increase this effect, a small strabismus hook is slipped through the incision and on this the incision in the muscle is lengthened without further cutting the conjunctiva. No suture of the conjunctiva is necessary and no bandage.

If preferred, a triangular flap of conjunctiva may be laid back, a small incision made through the capsule of Tenon either above or below so that a small hook can be passed under the entire muscle. In this position one can divide the median fibres more certainly and more freely than in the subconjunctival method, without danger of cutting the lateral fibres on either side which would leave the tendon attached by one corner and might produce torsion effects. A conjunctival suture is advisable here, but not necessary. It is especially useful if we wish to diminish the effect of the operation slightly, and it may be taken out in twenty-four to forty-eight hours.

Shortening and Resection Operations.—The general trend of ophthalmological opinion is in favor of resection rather than tenotomy, but there are certain logical reasons for preferring one to the other in a given case. For instance, if the imbalance is apparently due to abnormal weakness of one muscle rather than to the abnormal strength of its antagonist, an operation to restore the weak rather than to reduce the normal antagonist would be indicated. There are two types of operation done. The first, by an absorbable suture makes a tuck in the tendon. The disadvantages of the method are that the effect is not a large one and that the subconjunctival fold of muscle is somewhat unsightly for several weeks. The advantages are that it is difficult to overcorrect, the effect is permanent and there is no danger of torsion, and if the suture slips no great harm is done. The second method excises a portion of tendon and sutures the ends together.

This has a greater effect and produces no torsion, but if the sutures cut through, as occasionally they do, the effect is that of a tenotomy and exaggerates the original defect.

The Shortening—A triangular flap of conjunctiva is laid back over the insertion of the tendon, an opening in

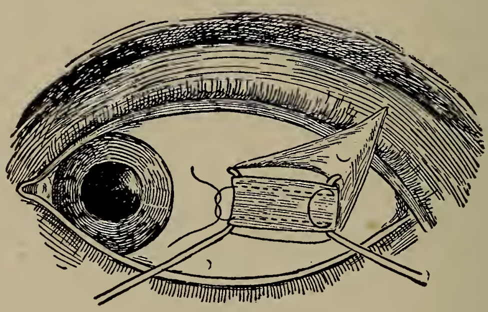


FIG. 95.

the capsule of Tenon made either above or below the muscle and two small strabismus hooks passed completely under it. These can be drawn apart by an assistant or the twin hook of Valk (Fig. 96) or the tendon tucker of Todd employed instead. One suture is then employed to bring the distal portion of the tendon up to the insertion, as shown in the illustration, the intermediate part forming a loop or fold. The suture material may be fine catgut (00) or preferably silk which is removed after a week. The conjunctiva may be brought together with a single stitch. This operation may be done under cocain and the reaction is not very great.

In the resection operation the tendon is laid bare in the same way and a suitable portion being exsected, the distal end is prevented from retracting by forceps and united to the stump by silk sutures. If silk sutures are used for either the resection or the shortening, they are best passed through the conjunctiva and muscle. The knots are thus readily accessible when the time comes for their removal and the same suture also serves to close the conjunctival wound sufficiently.

Esophoria.—Esophoria is characterized by an undue convergence of the visual lines for distance or near objects, or both, and may be due to the action of one or more of

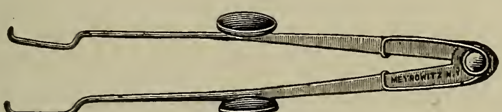


FIG. 96.

these causes, the first four being various stages of the same process.

1. Overstimulation of convergence from accommodation strain; 2. Excessive power of interni—convergence excess; 3. Defective externi—divergence insufficiency; 4. Combinations of 2 and 3; 5. Monocular imbalance due to hypertrophied internus or atrophic externus in one eye alone.

As these conditions vary considerably in their symptomatology and treatment, they should be studied separately.

FIRST STAGE: ACCOMMODATIVE ESOPHORIA.—This is evident only when accommodation is active but in time leads to anatomical changes causing permanent esophoria.

It will always be more marked at the near point while it may possibly be entirely wanting at the far point of the eye.

In pure cases the Maddox rod and vertical prism tests all show more or less homonymous diplopia, which is diminished or abolished by correction of refraction or atropin.

Fusion tests show a *slight* increase in convergence proportion as compared to divergence.

Tropometer tests show normal voluntary rotation of the eyes.

Equilibrium tests at the near point, like the screen test and the vertical diplopia test, show a very marked esophoria which diminishes greatly under proper refractive correction. It must not be forgotten that a convex sphere or cylinder is ordinarily centred for distant vision, but that in near work the visual lines pass to the inside of the optical centres.

Such a lens not only reduces esophoria by lessening accommodation, but also has the further effect of a prism base out.

The treatment consists of a careful correction of the refractive error, generally under a cycloplegic, and the use of the full correction for all close work. It may be judicious in many cases to reduce this correction for distance with a view to more satisfactory sight.

SECOND STAGE: CONVERGENCE EXCESS results from the hypertrophy of the interni, which follows the preceding accommodative overstimulation.

Position of rest shows some convergence of visual lines as shown by Maddox rod and vertical diplopia tests, the homonymous diplopia persisting in spite of refractive correction, and increasing when the gaze is turned to the right or left. Prism convergence is increased and divergence somewhat reduced, the proportions instead of 3 to 1, being 4 to 1 or 5 to 1, and holding this ratio pretty persistently. Tests at near points show esophoria.

Tropometer tests show an increased inward rotation of the eye without any diminution of the outward rotation, about 55 degrees in and 45 out.

The treatment consists in first, the full correction of the refractive error under a cycloplegic which will, in many cases, relieve all subjective symptoms and in time allow the muscles to assume their normal size and power. Exercise of the externi with prisms is of rather doubtful value, but it is at times helpful. Operative treatment should be a last resort except in extreme cases, since while the immediate results in the way of relief of pain are always good, the remote ones of creating an exophoria by over-effect should not be forgotten. Logically the preferable operation would be a slight tenotomy of both interni. A shortening of the externi, while more formidable and conspicuous for a longer time, is equally satisfactory from a clinical standpoint.

THIRD STAGE: DIVERGENCE INSUFFICIENCY WITH CONVERGENCE EXCESS is generally the result of a breaking down of the externi by overaction of the interni which become hypertrophied in the process. In many of the cases we can trace the progress beginning with a pure accommodative esophoria followed by, at first a convergence excess and later by the divergence insufficiency.

The symptoms are very marked at a distance and increase near at hand.

These are the cases which pass over into convergent squint.

Position of Rest.—Marked homonymous diplopia by all tests.

Fusion Tests.—Divergence very much reduced and badly maintained, perhaps 1 △ or 2 △. Convergence very much increased 30 △ to 60 △. After testing the interni, spasm often develops so that for the time divergence disappears altogether and a spontaneous diplopia is present.

Tropometer tests show a marked increase of inward rotation and a marked deficiency in the outward, 55 in and 35 out, for instance, in each eye. Operative treatment is the only one that is likely to be helpful in these cases, though, of course, the refractive error as the probable first cause should be carefully corrected. The operation will consist of shortening or advancement of the underacting muscles or tenotomy of the overacting, according to whether the convergence excess predominates or the divergence insufficiency. Not infrequently both will be necessary. If tenotomies are done, they should be guarded ones for fear of producing overeffect and as a rule it is better to get all possible effect from a shortening of the externi and some time later tenotomize the interni very carefully as much as seems necessary.

Divergence Insufficiency is rarely due to a weakness of the externi without any change in the interni. Naturally its symptoms will be more noticeable in those tests of the eye which call for the greatest action of the externi, namely distant vision, and will diminish or disappear at the near point.

Position of Rest.—Maddox rod, cover test and vertical prism, all show marked homonymous diplopia, increasing eyes right or left, which diminishes or disappears when the object is brought up to the reading distance.

Fusion tests show a diminished divergence, the externi being able to overcome only very weak prisms and this diminishes rapidly under test. The interni are ordinarily about the average normal, certainly there is no great increase in convergence and not infrequently it is diminished, but the proportion of convergence to divergence increases from 3 or 4 to 5 or 6. Very often the externi becomes so fatigued during the fusion tests that afterward there is a homonymous diplopia for a time with a red glass or even the naked eye.

Tropometer tests show a lessened outward rotation of each eye with no increase or only a slight increase in the inward movements.

Treatment consists of refractive correction as a matter of routine without any expectation that it alone will be enough. Prism exercises are hardly worth a trial and the wearing of prisms, base out, with the idea of helping the externi, will be only temporarily beneficial, since the ultimate effect will be to exercise the interni and so exaggerate the original condition. Operative treatment may be anticipated from the first and the logical operation is a shortening or an advancement of the externi since a tenotomy on the interni which are already not overstrong might improve conditions for distance, but would substitute new difficulties at the near point.

Overaction of one Adductor or Underaction of one Abductor.—These conditions are sometimes congenital defects of muscular insertion or bulk and sometimes the result of injury or disease and very often of previous operation on the eye muscle. Evidently, if only one muscle be involved, the esophoria will be more marked in the field of this muscle. For instance, if the right internus be involved, there will be by the *rest tests* homonymous diplopia which will increase when the strong muscle is in action as in turning the eye to the left, and disappear entirely when the strong muscle is relaxed as in turning the eye to the right. But the same thing will occur if, instead of an overacting right internus, we have an underacting right externus.

The *fusion tests* are of no help in finding which muscle is at fault, for the fusion power, whether in divergence or convergence, is limited by the capacity of the weaker muscle of the pair. The right internus cannot manifest its full power, because long before that is reached the left internus has given out and the left eye diverged.

The tropometer is the most reliable test in these cases, because it indicates definitely whether both muscles or only one are involved, and exactly which. For example, R.E. 50 x 45, L.E. 60 x 45, shows an overacting left internus; R.E. 50 x 45, L.E. 50 x 40, an underacting left externus and R.E. 50 x 45, L.E. 60 x 35, would indicate both together.

The treatment of these cases, if they occasion symptoms, is operation on one eye, either weakening the overacting strong muscle or strengthening the underacting, or both.

Exophoria denotes a tendency of the visual lines to diverge for objects at a distance or near at hand, or both. Except for the intervention of the fusion compensation, it would cause diplopia and even when overcome, it causes symptoms, depending on the amount of defect and the proportion of compensating power. If the exophoria is due to the presence of interni which are long and lax, but not wanting in strength, the diplopia will be overcome by a very slight effort and may cause no symptoms of any kind. On the other hand, it may be due to the actual muscular imbalance, either over-powerful externi or weak interni, or both together. In either case the patient may be able to fuse distant images without obvious effort, but in near vision his eyes have to be converged through a wider arc than normal by interni which are either intrinsically weak or burdened with too much opposition by strong externi. Near vision is a matter of abnormal effort and if at all continuous, results in diplopia, with the suppression of one image or in reflex symptoms in direct proportion to the effort involved. The first is painless, but deprives the individual of the advantages of stereoscopic vision. He sees everything in the flat and has but slight facility in estimating and measuring. If, however, fusion is constantly attempted, the patient suffers all the disabilities already referred to. In exophoria then, the subjective symptoms are slight in distant vision and increase progressively with the closeness and continuance of near work.

As the treatment depends entirely on the cause, a very careful application of the tests referred to in the previous chapter must be made.

Accommodative Exophoria.—Just as esophoria may be due to excessive accommodation, so exophoria may be due to lack of accommodation. The myope, for instance, who sees best with his accommodation completely relaxed, not infrequently shows an exophoria for distance which is very much more marked in near work which calls for increased convergence with little, if any, accommodation.

Position of Rest.—All tests show cross diplopia, not necessarily very great for distance, but increasing markedly nearer at hand and disappearing entirely when proper refraction is secured.

Fusion tests are not very reliable in myopia because fusion depends to a great extent on sharp vision which can only be secured in many cases by strong concave glasses. If tested without glasses, divergence is apparently somewhat above normal. A portion of the prism overcome, simply allows the eye to assume the position of rest without diplopia and does not necessitate any muscular effort, and if we add to this the further prism which is overcome by actual muscular contraction even if it be subnormal, the apparent prism divergence is increased. In measuring prism convergence the eyes start from a position where some of the convergence energy is already expended to secure single vision and in addition is deprived of the additional stimulus which should come from sharp vision and some accommodation. Consequently, convergence is generally subnormal.

It might seem at first sight as though fusion ought to be tested through proper myopic lenses. If, however, the myopia be a high one, the instant the eye diverges from the optical centre of the lens, the lens acts as a prism, base out, and nullifies part of the prism used in the test. In converging, the eye looks to the inner side of the optical centre of the correcting lens which here acts like a prism, base in, and nullifies the action of the prism used in the test. The prismatic action of the myopic glass increases progressively the further from the centre, and consequently, as the eye normally converges far more than it diverges, the error in the estimate of prism convergence is far greater than in prism divergence.

The tropometer test will show a normal rotation in all directions in exophoria due to lack of accommodation.

Treatment.—Correct refraction in full under cycloplegic.

Convergence Insufficiency is due to lack of power or innervation of the interni and the symptoms will naturally be slight or wanting at a distance and increase progressively as close work throws strain on these muscles.

Equilibrium tests negative for distance or showing very moderate × diplopia. Very marked × diplopia for near, cover test showing distinct redress movement inward.

Fusion Tests.—Divergence normal or increased; convergence much reduced and badly maintained. × diplopia very frequently after fusion tests showing temporary exhaustion of interni.

Tropometer shows outward rotation normal or slightly increased. Inward rotation reduced and growing less on repeated trials: 40° inward by 45° outward is a fair example.

Treatment.—Correction of refraction especially if myopic. These are the only ones that are markedly benefited by exercise several times a week with prisms base out and carried to the point of fatigue, conjoined with rest from near work and attention to the general health. If improvement does not result or is not reasonably permanent, a shortening of one or both interni is the logical resort. Slight tenotomy of the externi, while not logical, yields good clinical results, but is very likely to cause a divergence insufficiency.

DIVERGENCE EXCESS is due to overaction of the externi, the interni being normal. The symptoms are therefore likely to be more noticeable at distance than in near vision. Subjective symptoms often *nil.*

Equilibrium Tests.—Very marked × diplopia for distance by all tests. Much less marked or wanting entirely for near points.

Fusion Tests.—Prism divergence much increased, 10^{Δ} or over. Prism convergence good, but not proportionate.

Tropometer tests show increased outward rotation with normal inward rotation; 50 x 50 is a fair example.

Treatment.—Complete correction of refraction, especially if myopic. Exercises calculated to weaken the externi and develop the interni may be tried. Operative treatment is seldom necessary, the logical choice being slight tenotomy of both externi. Clinically there is no objection to a moderate shortening of one or both interni.

Divergence Excess with Convergence Insufficiency.—This implies overacting externi and weak interni. The symptoms will be manifest not only at distance, but will be increased in near vision. These are the cases that easily pass over into divergent squint.

Equilibrium Tests.—Marked × diplopia by all tests at distance and increased in close work.

Fusion tests show increased prism divergence and prism convergence much reduced or wanting entirely. Where present, it is badly maintained and frequently after testing the fusion powers the interni are so exhausted that spontaneous × diplopia is present.

Tropometer tests regularly show increased outward rotation and reduced inward; 35° in x 55° out in each eye for example.

Treatment consists of tenotomy of overacting externi. Systematic exercise of interni and shortening, if necessary, later on.

Hypertrophy of one Externus or Weakness of one Internus may be due to a congenital anomaly of strength or insertion, disease, or is often the result of operation for squint in childhood. The symptoms will be most marked in the field of the abnormal muscle, and either slight or altogether wanting in motions of the eyes which do not involve the abnormal muscles. For instance, in overaction of right externus.

Equilibrium test shows × diplopia for distance and near, which increases on turning the eyes to the right and diminishes or disappears on turning eyes to left, which might mean an overacting right externus or an underacting left internus. Near tests show diplopia, and if fusion is possible it is much easier on carrying the object to the left so as to use the normal right internus and left externus. Fusion tests are of no value in monocular imbalance for reasons already explained.

Tropometer tests are of the utmost value, showing at once the muscle involved. For instance, a reading of R. 50° in x 45° out, L. 50° in x 55° out, shows at once an overaction of the left externus, while R. 50° in x 45° out, L. 40° in x 45° out, would plainly indicate a defective left internus.

The treatment of such a condition is essentially operative, since there is no way of exercising a single muscle without a corresponding effect on its fellow in the other eye; and the operation selected should be a shortening of the defective muscle or a tenotomy of the overacting one in proportion to the correction desired.

Hyperphoria.—We should group under this head all the vertical deviations of the visual axes since the diplopia is the same whether one eye be turned up or its fellow slightly down, one image appearing directly over the other. This is a very important muscular defect since the facility in fusing vertical images is very slight indeed, the prism power of the elevators being only 2° and that of the depressors only 3° or 4°. A comparatively slight vertical error then completely abolishes the fusion power of the eyes and allows the eyes to assume the position of rest. In this way a slight hyperphoria will prevent the suppression of an esophoria or exophoria which would not be noticed at all if the images were on the same level. In such cases the lateral diplopia is often so much greater than the vertical that the latter is unnoticed when it is by far the most needful of attention. It may be due to overaction of an elevator or underaction of a depressor in one eye, or the reverse condition in the other eye, and it will often tax our ingenuity to ascertain which muscle is involved. For purposes of record it is the custom to designate a vertical diplopia as a right diplopia or a left, according as the image in the right or left eye is the lowest.

Equilibrium tests (prism base in, Maddox rod, red glass) show a vertical diplopia. If the right eye image is the highest (left diplopia), it indicates that the right eye is pointing lower down than the left. If the vertical diplopia increases on looking upward we have to do with an underacting right elevator or overacting right depressor, But the defect may be in the other eye, as for instance, an overacting left elevator or underacting left depressor, causing the left eye to point too high. The effect that the obliques have on the elevation and depression of the eyes must not be forgotten. However, if we can exclude any involvement of the oblique muscles by the crossed Maddox rods or the Maddox double prism, we have simplified our problem materially. A vertical diplopia which increases greatly when the eyes are turned in one direction, and diminishes or disappears in the opposite, comes under the head of paralysis rather than hyperphoria (see page 303).

Prism fusion tests in hyperphoria are not helpful, since even in normal eyes fusion of vertical images is slight and variations from the standard are usually slight except in conditions bordering on paralysis. Moreover, since each eye has four muscles which may be concerned in hyperphoria, a test which is not capable of distinguishing their separate actions is more confusing than helpful. The increase of the diplopia as shown by the equilibrium test when the eyes are moved in various directions is somewhat more helpful. For instance, a left diplopia increasing as the eyes turn upward and diminishing as they turn downward would evidently be due to an overaction of the right elevators or underaction of the left depressors.

The tropometer is the most reliable and exact method of identifying the muscle at fault, but even with this much more than the usual care must be taken to obtain a position of the head with the eyes on a level and to be certain that the head is not moved during the tests. As we have seen, the upward and downward rotation of the eyes varies greatly with the position of the head whether tilted forward or backward, but it ought to be equal in both eyes. If we find that the right eye rotates upward 30° and down 35°, while the left rotates upward 20° and down 35°, there is evidently a deficiency of the left elevators. If the rotation is 30° x 45° it reveals a deficiency of left elevators. 20° x 55° shows overaction of left depressors, 40° x 25° shows overaction of right superior and underaction of right inferior, 20° x 45° shows underaction of left superior and overaction of left inferior.

Furthermore, by aid of the tropometer we can definitely measure the rotating ability of any one of the straight muscles by placing the eye in such a position as to nullify the possible elevating and depressing action of the obliques.

For instance, when the head is in a symmetrical position the right eye is elevated by the superior rectus and inferior oblique, but if we turn the head in the headrest so that the eye is turned slightly outward, the obliques produce only a torsion effect and any elevation of the eye must be due to the superior rectus unaided, while any depression must be due to the inferior rectus.

Treatment.—Hyperphoria is a very important element in heterophoria and very often overlooked, and since the fusion power over vertical diplopia is very slight indeed, the equilibrium tests have in this variety of imbalances an importance that they attain in no other. As we have seen, when the error is slight, the patient can compensate by tipping the head to one side so as to elevate one eye and depress the other, but this throws a constant strain on the obliques of keeping the vertical planes of the eyes from being also tilted.

The fusion powers are so slight and so incapable of development by exercise in this condition that exercises are of no special value. This fact is of particular importance, however, in the application and the prescription of prisms for permanent use, since prisms which place the images in the same plane are seldom very strong and the effect is permanent. For this reason prisms base up or down in either eye, as may be required, are more useful in this condition than in any other.

Operative treatment is seldom called for. Since the straight muscles are the ones chiefly concerned in elevating and depressing the eyeballs and since they are the most accessible, operations are confined to them. By aid of the tropometer we can ascertain which muscle is at fault and whether by overaction or underaction, so that theoretically a tenotomy of the overacting or a shortening of the underacting muscle would be indicated. Clinically, however, so long as the eyes are in the same plane, it makes no practical difference in most cases whether they go up as many degrees as they should, while it is of manifest importance that they should be capable of a considerable depression. Ordinarily, if a tenotomy is done, it should be on the superior rectus of the hyperphoric eye, since this will not limit the depression of the eyes as a pair, and since one is not so apt to get overeffect as from a tenotomy of the stronger inferior. For similar reasons a shortening, if done, should be done on an inferior of the hyperphoric eye, since this increases the ability to look downward and since the inferior is more easily reached in its continuity than the superior.

Dextrophoria and **lævophoria** have been suggested by Valk as terms to describe a condition in which both eyes are capable of abnormal rotation toward the right or left as the case may be, the movement in the opposite direction being restricted. In dextrophoria for instance, which is by far the most common, the patient can rotate his eyes toward the right 60° and to the left perhaps, only 40°. His position of rest is, then, with his visual lines parallel, but to the right and in looking at objects directly in front he is much more comfortable with his head rotated slightly to the left. It is difficult to account for, except on the theory that definite movement of the eyes is, in most occupations, rather to the right than the left. The position of the paper in writing at a desk tends toward a dextrophoria; in reading, we move our eyes steadily from left to right and then begin a new line by a single brief movement to the left; the things that a man, be he laborer or student, uses oftenest, he keeps within reach of his right hand and in referring to them he is constantly turning his eyes to the right.

The visual lines being parallel and the fusion powers generally normal, the condition is commonly overlooked, unless so extreme as to cause a marked turning of the head, but a routine use of the tropometer shows it to be very common, a typical record being R. 40° in x 60° out, L. 60° in x 40° out. Since dextrophoria is so easily compensated for by turning the head, it is so absolutely without subjective symptoms, even if it be not an actual advantage to a right-handed man, that it had better be left entirely alone.

It very often, however, results from other imbalances when it must be treated more carefully. For instance, suppose a patient whose right internus has been cut for squint, is paralyzed or congenitally defective. When he looks to the left he has a cross diplopia which vanishes to the right and he soon gets the habit of carrying his head in this easy position. Ordinarily, this will cause no discomfort, but if the left internus is so weak that it cannot follow the right externus to its position of greatest ease the visual lines are evidently divergent and the case must be treated as an exophoria. If, on the other hand, the left internus overbalances the right externus, the condition is an esophoria and must be treated as such.

Similar reasoning applies to the conditions known as **anaphoria** and **kataphoria** in which the visual lines are parallel to each other but directed up or down with regard to the horizontal plane of the body.

In the first, owing to congenital abnormalities, usually, the eyes tend upward and the individual must go about with his chin on his chest, that his eyes may look in front and yet remain in the position of rest. In the second, the chin is held in the air and the body arched backward, but unless extreme, neither causes more than cosmetic difficulty and both should be let alone, owing to the extreme difficulty of securing the same operative effect on both eyes. Suitable prisms are much more likely to be beneficial.

Cyclophoria is the condition in which the oblique muscles are no longer able to keep the vertical meridians of the retinas parallel. For instance, if the superior oblique of the left eye is defective, the vertical meridian rotates outward above and inward below. If the object of regard be a vertical line the right eye sees it vertical, while in the left the top appears tilted to his left and the bottom to his right.

The composite picture is that of an oblique cross and when the object of regard is of a nature not so simple as a single line, the distortion and confusion are very marked.

The diagnosis can be made by the method described in the previous chapter with the double Maddox rod, the Maddox prism or the clinoscope.

The treatment consists in exercise of the torsion powers with the same instruments or if this proves ineffectual, operative measures are strongly advocated by Stevens. Inasmuch as the oblique muscles themselves are inaccessible the internus is made to assume a torsion function in this manner. We have seen that the internus has a broad fan-like insertion, one-half above and one-half below the mid-line of the cornea. Now, if the lower half of the insertion is cut loose and allowed to slip back, the remaining half will evidently pull more on the upper end of the vertical plane and so assume in part the function of the superior oblique. The same purpose is subserved by advancing the upper half without touching the lower and the maximum effect obtained by combining the two. By reversing the procedure, the internus can be made to replace in part the inferior oblique. The treatment of cyclophoria is at present in the field of experimental surgery and should not be attempted except in case of absolute necessity and after the most careful testing.

CHAPTER XIII.

HETEROTROPIA—STRABISMUS—SQUINT.

Heterotropia, strabismus and squint are synonymus terms and mean that when the patient fixes an object with one eye, the other is so turned that the image ceases to fall on the macula. Squint is of two varieties: that in which the deviation is due to paralysis of one or more muscles, which will be discussed in another chapter, and the non-paralytic variety. In paralytic squint the deviation is perceptible only when the gaze is turned in such a direction as to bring the paralyzed muscle into action, and increases as the eyes are turned in this direction. In non-paralytic squint, on the other hand, the inclination of the visual lines toward each other is the same in every direction of the gaze. If we have a squinting patient regard a candle, he fixes it with one eye and turns the other in toward his nose. This deviation of the squinting eye is known as the *primary* deviation. If, now we cover this eye, the patient immediately fixes the candle with the other, and if we look behind the screen we shall find that this eye now deviates in exactly as much as its fellow did formerly. This deviation is known as the *secondary* deviation. The fact that the inclination between the optic axes is a constant one, the primary and secondary deviations being equal, has caused the term *concomitant* to be applied. In paralytic squint the primary and secondary deviations are not equal, as we shall see.

Measurement of Squint.—We have the patient look at a distant object and place a dot on the lower lid opposite the margin of each pupil. We then compel him to fix the object with the squinting eye and again, mark the position of the margin of the pupils by dots. This distance between

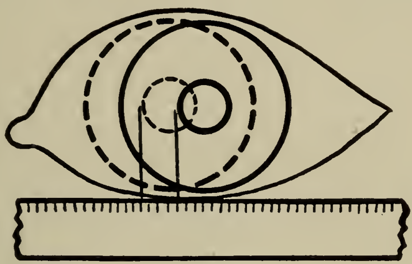


Fig. 97.

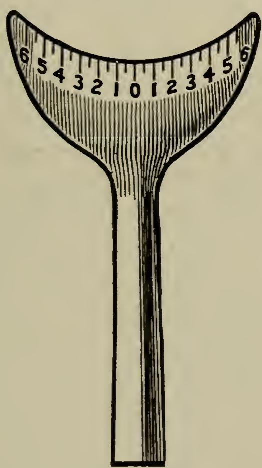


Fig. 98.

the two marks on the squinting eye measures the primary deviation and that between the marks on the other, the secondary. In concomitant squint they are always equal.

On similar principles is the strabismometer (Fig. 98), an ivory instrument, fitted to the curve of the lower lid. The patient is compelled to fix an object with the squinting eye and the centre of the instrument placed below the centre of the pupil. When he fixes the same object with the

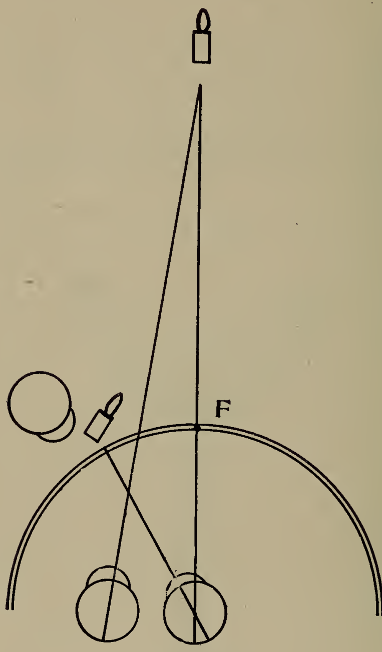


FIG. 99.

other eye, the amount of deviation in or out can be read off upon the scale. Both these methods are very crude and inexact.

If we place the squinting eye opposite the centre of a perimeter and have the patient fix the candle with both eyes uncovered, the squinting eye will deviate one way or the other from the centre. If we carry a candle along the arc of the perimeter, keeping one eye exactly behind it ourselves till the reflection appears exactly in the centre of the squinting eye, we shall have found the fixation point; and the number of degrees by which it varies from its normal position *F,* will be the measure of the squint in degrees.

These methods are all relative—squint cannot be measured exactly since it is often a variable quantity. For instance, if we have a patient fix a distant object, we find a very slight deviation or perhaps none at all, but if we measure him at the perimeter where he uses his accommodation, it is much more noticeable. In practically all cases of squint, changes, either primary or secondary, will be found in the muscles of the eye affecting their rotatory power, and these can be accurately measured by the perimeter or better still, by the tropometer as in latent squint. This is especially important when operative interference is contemplated, for an amblyopic eye is apparently always the squinting one, since fixation is always performed with its fellow. As a matter of fact, however, the muscular changes are often greatest in the eye which does not squint.

We should expect that when one eye fixes an object, its image will be formed at the macula and since its fellow deviates from the correct position its image must fall elsewhere and therefore, cause a diplopia. This does occur in paralysis and in the very early stages of concomitant squint, but the patient, by a psychical effort soon learns to keep his attention on the distinct macular image and to disregard the less distinct non-macular one. After a time the habit gets so fixed that even when both eyes see well it is very difficult or impossible to make the patient conscious of his diplopia. A squinting patient evidently cannot have stereoscopic vision and consequently his ideas of form, size and distance are much less accurate than normal.

The visual acuity in strabismic patients varies greatly. In many cases the acuity of the two eyes was originally equal, but after the patient gets the habit of suppressing the image in the squinting eye, it fails greatly from simple lack of use. This failure is called *amblyopia exanopsia.* In such an eye the acuity is capable of very great improvement, sometimes up to normal, by systematic exercise. In other patients there may be a *congenital* amblyopia in one eye which compels the patient to fix with the other, or the refractive error may be so great in one that any distinct vision is impossible without glasses. This causes a practical amblyopia exanopsia from birth. If corrected very early during the plastic period of childhood, the amblyopia may grow greatly less, but, if neglected, the amblyopia becomes permanent.

The amount of amblyopia varies greatly; in some patients vision is reduced to absolute inability to count fingers or less, and the eye has lost all its power of fixation, so that if its fellow is covered it maintains its position. In others a vision of 20/200 up to 20/30 is found and occasionally a patient is seen where the visual acuity of both eyes is practically equal. As a rule, however, the vision of the squinting eye fails steadily with the duration of the squint, from lack of use. It is, however, a macular amblyopia, since while incapable of distinct central vision, the field of vision is generally normal, the brain taking cognizance of peripheral impressions.

Apparent Squint.—There are a number of patients whose eyes diverge or converge to all appearances, but in whom, if one eye be covered, the other maintains its position showing that both images were formed at the macula and that the vision was binocular in spite of the apparent squint.

These cases are to be explained in this way. In the ideal eye the optic axis which is perpendicular to the cornea and the lens should pass through the macula and coincide with the visual axis. In most eyes, however, the macula is a trifle to the outer side of its proper location, so that a line from it to the object of regard passes through the nodal point and cuts the cornea a little to the inner side of its centre. But we judge the position of the eye from the cornea; therefore, if the macula is too far to the temporal side the visual lines will be nearer to the inner side of the cornea and the eyes appear to diverge, while if the macula were to the nasal side of the optic axis, the visual lines would pass to the outer side of the corneal centre and the eyes appear to converge. The amount of this apparent squint is determined by the size of the angle between the optic axis and visual lines known as *angle gamma*.

That the squint is apparent and not real is readily determined, since there is no movement of redress when the apparently fixing eye is covered, provided always that both have good vision. The size of the angle can readily be measured on the perimeter, the patient fixing a candle flame in the centre of the perimetric arc with one eye thus locating its visual line. The surgeon moves his eye along the arc with a small light till the reflection appears exactly in the centre of the cornea, when the optic axis perpendicular to the corneal centre must be exactly here and the degrees can be read off on the arc.

There are many different terms applied to concomitant squint most of which define themselves, as for instance *convergent, divergent* and *vertical*. In *alternating* squint the vision is about equally good in both eyes and sometimes the patient fixes with one and squints the other and again reverses the process. A *periodic* squint is one which is perceptible at times and again disappears. This generally occurs in the early period, the squint later becoming a constant one.

The etiology of squint is a vexed question. We have seen in a previous chapter that the ideal eyes are so muscled that in a position of rest their visual lines are parallel and that where this ideal balance is not present, the equilibrium is maintained by the fusion centres of the brain. These are the two factors governing the presence or absence of squint. If the muscle balance is normal, binocular vision, takes place without the stimulation of the fusion centres. If the muscle balance is abnormal while the fusion impulse is powerful, we have a latent squint which may or may not cause symptoms. If the fusion compensation is wanting or not great enough for the imbalance, we have an actual squint, the variety of which depends on the variety of muscle imbalance, and is periodic or constant according to the amount of fusion impulse available.

Let us consider these basal factors and some of the conditions which may interfere with the normal working of one or both.

Congenital Muscular Anomalies.—We have absolutely no means of knowing the actual muscular balance at birth and during early childhood, but bilateral bodily structures are seldom or never absolutely symmetrical, and there is every reason to suppose that most children have some muscular imbalance. But there are certainly in some cases congenital gross defects in the origin and insertion of one or more muscles, or abnormalities in the bony orbit due to asymmetrical bony development or disease, or injury at birth, which would preclude parallelism of the optic axes when the eyes are at rest. On this theory only can we account for those not infrequent cases of squint in which the muscular defect is in the fixing instead of the squinting eye. We should expect nearly all infants to squint more or less and most of them do from time to time to the consternation of parents. But unless the squint is great enough to be a cosmetic defect, it is not observed, for until they begin to fix objects we have no means of testing the position of the eyes except by the position of the corneal images which is a very inaccurate one, and any infant might have a squint of 5° to 10° without detection. The eyes converge and diverge at various times till the brain having developed sufficiently to be conscious of double images, a fusion impulse compels the eyes to coördinate. Where the muscular error is small and the fusion impulse strong, the squint becomes a latent one. On the other hand, where the anatomical defect is a large one and the fusion impulse weak, the squint becomes a fixed one. It is to be remembered that the stimulus to fusion is greater in proportion to the proximity of the images to the macula; consequently, in very great deviations where one image falls in the periphery of the retina, the fusion impulse is weak or may possibly not develop at all. If the fusion is possible, but requires too much effort, the brain finds it much easier to suppress one image. Then it is anatomically much easier to fuse images in one direction than in another. For instance, vertical diplopia can be compensated for very poorly. The divergence power of the eyes is not much greater so that nature has great difficulty in rectifying a convergence, while a divergence of the optic axes is rectified with ease. For these reasons convergent squint is very much more common in children than any other. The relative frequency of vertical squint in early childhood we know nothing about, because we have no means of detecting low degrees of squint applicable to children. For these reasons we must think that most of the squints that develop within the first two or three years of life are probably due to congenital anatomical defects which are beyond the fusion power's correction or which even prevent the development of that power. But that comparatively few cases of squint are due either to congenital imbalance or failure to develop fusion power, is indicated by its relative infrequency in blind asylums among patients who have been blind since very early infancy and can never have developed any fusion power.

There is another type of cases which is not evident till later in life at the age of five or six, long after the fusion power is ordinarily established. If it were due to a congenital abnormality of muscle and failure to develop the fusion faculty, it would have appeared earlier, and it is evidently due to a muscular anomaly not congenital, but acquired, and a suppression of the fusion faculty which was previously developed.

Since muscular changes are the primary conditions, let us consider the conditions which may cause changes in muscular balance.

Refraction.—Donders long ago pointed out the intimate association between refractive conditions and squint. As we have previously seen, there is a very intimate relation between convergence and accommodation, and the individual who through hyperopia or astigmatism has to overaccommodate, automatically overconverges. Except for the sufficiency of the fusion compensation, all such would finally pass from the condition of latent to that of fixed squint. Even in middle life exercise of the interni causes hypertrophy to a much greater extent than does exercise of the externi and in the plastic period of childhood the hypertrophy in muscle is not temporary but often a permanent increase in bulk and strength. Where this hypertrophy overbalances the fusion ability, double vision occurs for brief periods long before any squint is perceptible, especially at periods of unusual strain as in school. Each failure to fuse weakens the fusion impulse, and the convergence meeting less resistance increases rapidly, the patient learning to suppress one image completely, and the fixed squint has been established. But this does not explain divergence which occasionally occurs in hyperopia. We must bear in mind the effect on a muscle of stimulation, which within physiological limits causes hypertrophy, but when carried beyond the power of the muscle to respond causes it to lose its responsiveness and results in atrophy. In childhood when the muscular metabolism is most active, hypertrophy generally occurs with convergent squint, but in maturer years divergence in connection with hyperopia is much more common, especially when the fusion faculty is suddenly interfered with by some accident or injury. In childhood, when hyperopia is so high as to be entirely beyond ciliary compensation, we have seen that a child frequently holds objects very close to the eye to secure a large, though indistinct, retinal image, perhaps not accommodating at all. In such a case the strain of converging constantly at a point only two or three inches away would be tremendous and would certainly lead to hypertrophic interni; if any attempt were made at binocular vision the result could hardly be other than that of hypertrophy with convergent squint or of atrophy with divergence. But in most of these cases the vision is so poor that accommodation or fusion stimulus is practically *nil* and often no changes in the muscles occur at all.

The conditions in myopia are very different. Allowing that a child is born with normal muscles, his distant vision is so much reduced by his myopia that fusion instincts are not called into play till the period of close work arrives. In a myope of 4 D. for instance distinct vision is only possible at ten inches and this with a complete relaxation of accommodation. Here again the normal relation between accommodation and convergence is disturbed and the impulse to converge is weak, and if the fusion impulse is not a strong one divergence occurs. But young people notoriously do not hold their work at their far point but bring it closer, because they can thus, by accommodating, both obtain sharper vision and aid in the convergence impulse. The customary fixation point is abnormally close and though no squint is present, the inclination of the visual lines toward each other is often far greater than in those of a squinting hyperope. This results in young children in an overdevelopment of the interni. If the myopia is a high one, the interni break down under the strain of binocular vision so near by and divergence begins. Even in the more moderate and stationary myopias, with age and increased hours of labor, the interni become more and more insufficient, and divergence becomes more frequent, while in the progressive cases the already overtaxed interni are loaded with the increasing proximity of the far point and the failure of a sharp fusion impulse through fundus disease.

But very considerable muscular imbalances may be present without actual squint provided the fusion power be good. Let us consider some of the factors on which fusion depends, a sharp image and a normal cerebral reflex action.

Any cause which reduces the visual power of one or both eyes diminishes the fusion stimulus and lessens the power to compensate for slight muscular imbalance. For this reason opacities in the cornea, lens and vitreous and changes in the fundus are often followed by manifest squint of some sort which was before latent.

Refractive difficulties when not compensated also reduce vision and lessen fusion.

In hyperopia and hyperopic astigmatism vision is better at a distance, the fusion stimulus greater and the squint not marked. Near at hand however, not only is the tendency to squint increased by the accommodation strain, but the fusion power is much reduced if the near vision is defective. In myopia, on the other hand, distant vision is bad, the fusion stimulus small and the squint more marked, while in near vision the images are distinct, the fusion good and the squint often imperceptible.

The cerebral element in fusion is also very important. Some individuals never show any tendency for binocular vision and are not annoyed by diplopia even though vision be normal in both eyes.

The condition of amblyopia, so very commonly present in squinting eyes, is an interesting one, meaning a reduction in vision without any demonstrable lesion. By some this is considered congenital and, through the reduction in fusion power, the cause of squint, while others consider that it is generally secondary to squint and results from lack of use and suppression of the image in the squinting eye. Retinal hemorrhages are extremely common in the newborn and a small macular lesion would easily account for a congenital amblyopia. The very high amblyopias in which vision cannot be brought above 20/200 are probably, but not certainly, congenital. They rarely improve though a few cases are recorded. The partial amblyopias of 20/70, 20/50, etc., are very often improved by forced use of the amblyopic eye and are therefore amblyopias exanopsia or from disuse.

There is a very general lay belief that squints develop very suddenly early in life as the result of fright, bright light, illness of various sorts and other circumstances which occur in the life of every child. There is so far as we know no scientific basis for such a belief, but most impressions which are so universal have at least a basis of truth and are not to be neglected entirely. Perhaps the fusion impulses are thus inhibited for the first time.

Spontaneous cure of strabismus of the convergent type not infrequently takes place after the patient reaches the age of twenty-five or thirty. These cures are to be explained only on the theory that the squint is not a primary one, but was due to overstimulation of convergence in hyperopia. As the patient gets older, the elasticity of his lens gets less, and he gradually ceases accommodative efforts which no longer produce any result. With the lessened accommodation the convergence stimulus is also less, the muscles gradually lose their hypertrophy, and the muscular balance is so nearly restored that no perceptible squint remains. Careful testing would probably show that in most of these cases a latent squint remains.

Treatment of Squint.—For purposes of treatment cases of strabismus may be divided into two great classes: those in which vision in both eyes is relatively good or can be made so by glasses, and those in which one eye is so amblyopic as to be practically blind with no reasonable hope of improvement. In adults and older children this is not difficult to ascertain, but in young children it will very often tax one's ingenuity.

One can obtain an approximation of the visual acuity in each eye by placing on the floor small white marbles and noting the distances from which the child is able to go to them directly with each eye. If the vision in both eyes is fairly good, the prognosis for cure without operation is much better than when one eye is highly amblyopic. But we must not decide that an eye is hopelessly amblyopic in a young child without repeated examinations. Both eyes should now be thoroughly atropinized and the refraction exactly estimated which can easily be done by aid of the retinoscope. In many cases the squint will entirely disappear while the patient is under the mydriatic which is proof that it is essentially an accommodative squint. In this case the constant wearing of the full correction with perhaps the use of atropin for some time till the muscles lose their hypertrophy, will result in a complete cure. When the child has already developed a tendency to fix with one eye constantly, it is always advisable to compel the use of the other for some time each day by a pad or bandage. In this way very great improvement in the poorer eye often takes place.

Accurate estimation of the refraction and constant wearing of the full correction is a *sine qua non* of all non-operative treatment of squint. Squinting children generally have a higher error in the squinting eye than the other, and careful refraction places the two on a footing of equality and makes possible the improvement of an amblyopic eye. If it makes vision sharp and distinct in each, it stimulates to the utmost the fusion impulse whether the object of regard be near or far. In addition it reëstablishes the normal relation between convergence and accommodation. In many cases it will be found that under proper glasses the squint persists when the eyes are used for near work, showing that the interni are still hypertrophied and unduly active under the slightest accommodative stimulus. Such children should be kept under atropin for weeks and, if necessary, can have a + 4 D. bifocal cemented on their distance glasses for the time as in presbyopia. Many parents will object to putting glasses on children at the age of two or three years, but it is much preferable to an operation which at this age cannot possibly

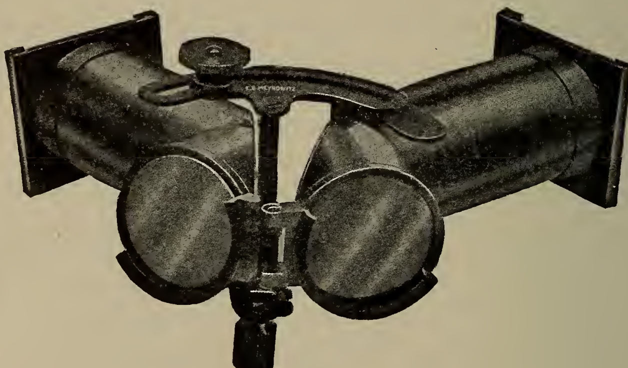


FIG. 100.

be an intelligent one, though it may result in a cosmetic cure.

It is in such eyes that the exercises with the stereoscope or the amblyoscope of Worth are especially helpful, as they not only stimulate the fusion but directly exercise the weakened extrinsic muscles of the eye.

This instrument consists of two tubes, each provided with a mirror and joined together by a hinge. By means of this construction the tubes may be brought together to suit a convergence of 60 degrees or separated to suit a divergence of 30 degrees. The eye pieces have a focal distance equal to the distance of the reflected images, which consist of transparent pictures placed in the grooves at the end of the longer tubes. Dr. Black has added to the instrument an additional movement in the vertical direction, in order to obtain fusion when the lateral deviation is complicated by a vertical deviation. This vertical adjustment is effected by turning the milled head mounted on the shaft extending down from the hinge. In Worth's own words the instrument is used for the orthoptic treatment of squint in the following manner:

"The child, with his correction on, is held on the surgeon's knees and the amblyoscope roughly adapted to his degree of deviation; it is then held before the child's eyes and an electric lamp is put in the axis of each tube about four feet away. By a simple mechanical arrangement each lamp is easily brought nearer to, or put farther away from the tube which it illuminates. A slide showing a cage, for instance, is put in the tube before the child's fixing eye, and a bird in that before the squinting eye, and the child is told what to look for. At first he sees only the cage. The lamp before the fixing eye is then taken farther away and that before the squinting eye is brought nearer until the child sees the bird. By this time he has lost sight of the cage. The child is then allowed to grasp the instrument, and, assisted by the hands of the surgeon, is taught to vary the angle of the instrument so as to make the bird go in and out of the cage. Many other similar pairs of slides are shown. The average child of 3½ or 6 years of age takes a very keen interest in the game which he imagines has been devised merely for his amusement. Slides which require a true blending of the images are then shown. After a time it is often found that the angle of the instrument may be altered to a very considerable extent, either in convergence or divergence, while the eyes follow the objects and maintain fusion of the pictures. One often gets a powerful 'desire' for binocular vision in these young subjects with surprising facility. The next step is to equalize the intensities of the lights. This may usually be done at this stage without a return of suppression. In many cases one is able to deviate the two halves of the amblyoscope more and more at each visit until parallelism of the visual axis is obtained."

The great disadvantage about all non-operative methods is that they take vast amounts of time and patience both on the part of the physician and patients, and in many cases where parents are of a low order of intelligence it is advisable in the beginning to put the eyes as nearly as we can in a normal position as soon as we discover that careful refraction and atropin are not likely to be successful. As a rule, however, operations on eyes with good vision should be postponed till at the age of six or seven it becomes possible to estimate more accurately the muscular condition and operate intelligently. This is especially important when we stop to think that a child who squints has either learned to suppress one image or they are so far apart as not to distress him. If now by an ill-considered operation we bring those images close together, but without restoring a normal muscular balance, we may have obtained a beautiful cosmetic result but at the cost of putting on the child all the muscular strain and headaches that often attend latent squints, and that just as he is entering on the ocular strain of the schoolroom. From the standpoint of comfort and ability to study he was much better off before the operation.

In latent squint we had three sets of tests of the extrinsic eye muscles: those which gave the position of the axes in a state of rest, those which estimated the involuntary or fusion power and those which tested the voluntary muscular power. In actual squint the patient has become so accustomed to suppressing one image that we cannot make use of the static[1] and fusion tests and must depend entirely on version tests with the perimeter or tropometer (see page 238) and these tests should be carefully and repeatedly applied to all possible cases before operation. These tests are especially important as enabling us to determine whether the muscular imbalance is divided between both eyes, in which case it was probably secondary to refractive difficulties and may disappear with their full correction, or whether it is confined to one eye, in which case it is probably primary, congenital defect, likely to persist without operation. The conditions found are exaggerations of those found in latent squint, and the operative treatment is along the same lines.

In binocular convergent squint, even though the patient always fixes with the same eye, we invariably find an increase of inward rotation associated with a decrease of outward, both being about equally divided between the two eyes. As a rule these are hyperopic patients who first developed an esophoria from over-accommodation. As the interni increased, the externi proved unable to resist the strain, gave way, and a squint resulted, at first periodic in times of fatigue, and later a constant one as soon as the patient acquires the habit of suppressing one image. This habit is easily acquired in a day or two and explains the rapid development of squint, the antecedent latent condition being unsuspected. Typical tropometer measurements in such cases are:—

[1] Duane's test (page 222), however, is a very useful one.

R.E. 30 up, 50 down; 60 in, 30 out;
L.E. 30 up, 50 down; 60 in, 30 out.

The monocular convergent squints show an entirely different set of measurements. In these perhaps one internus is congenitally larger or inserted nearer the cornea than its fellow in the other eye, or there may be a congenitally defective externus. In such a case equal innervation will rotate one eye inward further than its fellow and squint appears. But the patient always fixes with the eye that sees best and it not infrequently happens that the muscular defect is in the fixing eye and not in the squinting one. A typical measurement would be:—

R.E. 30 x 50 50 x 45
L.E. 30 x 50 65 x 35.

In this case, if the right eye has the best vision, the left would turn in. If the reverse were the case, the right would turn in and the patient would be apt to carry his head turned a little to the left so that he might look in front and still keep his sharpest left eye in its easiest position slightly rotated toward the mid-line. Any operation on the apparently squinting right eye would result in a condition something like this:

R.E. 35 in x 60 out
L.E. 65 in x 35 out.

In other words, the axes would now be parallel but the patient could turn both eyes much further to the right than the left, or a condition of dextrophoria would result which would compel the patient to keep his head turned to the left in order to see comfortably before him.

Operation.—After we have determined the muscle or muscles at fault, we can decide intelligently which operation to do. As a rule the shortening and graduated tenotomies alone are entirely ineffective in actual squint, and the choice lies between their combination, complete tenotomy and advancement.

As a matter of theory the advancement of a weak muscle ought always to be accompanied by an equal tenotomy of its antagonist. The tendency of late years is to advance one or both externi in preference to tenotomy of the interni, which was a few years ago the universal practice, but which had the disadvantage of sometimes producing an unsightly sinking of the caruncle and sometimes of producing an overeffect. The great advantage of tenotomy over advancement is that it can even in comparatively young children be done under cocain. In an extreme binocular convergent squint a strong advancement of both externi under ether is advisable and then after a few weeks, if the result is not sufficient, partial or complete tenotomy under cocain can be used to supplement the original operation.

The same reasoning applies to cases in which the muscular anomaly is in one eye alone, choice being made of an advancement, tenotomy or a combination of the two, according to the amount of effect desired.

In a previous chapter the operations for the shortening of a muscle or the exsection of a portion with a subsequent suture of the ends have been described and illustrated. A still greater effect may be secured by the following operation. The conjunctiva is laid back over the insertion of the chosen muscle which is caught upon a strabismus hook and a sufficient portion excised, the distal end being prevented from retracting by being grasped by suitable forceps. A silk suture with a needle at either end is then employed, one needle being passed through the upper corner of the distal end and the other through the lower corner. The upper suture is then carried beneath the conjunctiva till it emerges above the cornea while the lower suture has a similar position below the cornea. By traction on these the stump of the muscle can, if necessary, be brought clear up to the edge of the cornea by undermining the conjunctiva. If tied in this position the thread would pass directly over the cornea and to avoid this we have an assistant rotate the eye to its proper position with forceps and then pass the

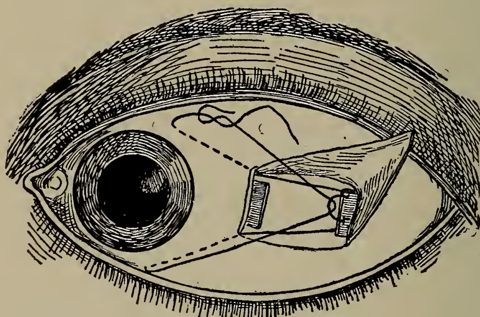


Fig. 101.

lower suture back through the loop left in the stump of the muscle and knot it firmly to the upper suture after drawing both reasonably tight. In this way the cornea is avoided and the loop acting as a pulley, the traction on the two sutures is equalized. The effect of an advancement is sometimes lost by the sutures pulling out, thus converting the operation into a tenotomy and increasing the original defect. This can be obviated by stretching the opposing muscle by several tractions on it with a squint hook, thus paralyzing it for a few days and taking the tension off the advancement sutures.

The operation of tenotomy in strabismus can be varied according to the amount of effect desired. The capsule of Tenon is reflected back upon the straight muscles a short distance like a sleeve and there are many fibres connecting the two. In the so-called graduated tenotomy a small opening is made in the conjunctiva over the insertion of the muscle and then the central fibres of both muscle and capsule are picked up with fine forceps and snipped. This causes a very slight effect and one which often disappears after healing, because only the central fibres of the muscle retract. A greater effect is produced by uncovering the insertion of the muscle, making a small opening in the capsule at its border, so that a hook can be passed beneath it and then cutting the tendon and that portion of the capsule which lies directly over it. Much of the capsule remains, so that there are many bands which prevent the complete retraction of the muscle.

In the classical tenotomy the blunt-pointed scissors are made to undermine the conjunctiva over the capsule clear down to the end of the capsular sleeve. A hook introduced here raises up both capsule and muscle when it is drawn toward the insertion of the muscle and both are cut off. The hook is then passed upward and downward under the conjunctiva to make sure of getting all the muscular fibres since in squint the insertion is often in the shape of a fan. When the operation is complete there are few or no bands connecting the muscle to the eyeball and the greatest possible effect is obtained. Unfortunately the extreme retraction often causes an unsightly sinking of the caruncle and in some cases the muscle entirely fails to become reattached to the eyeball and an actual divergence follows. This sometimes occurs several years after operation while limited inward rotation of the eye is very common. This extreme retraction is sometimes controlled by forcibly stretching the muscle with the hook before cutting it, rotating the eyeball outward till the cornea disappears at the external canthus. This paralyzes the muscle for a day or two and it does not retract so far. This manœuvre increases the temporary effect and lessens the permanent one. Too much emphasis cannot be put upon the extreme caution which should be used in doing complete tenotomy of an internus. Resection or shortening of the externus with only partial tenotomy of its antagonist is much the safer plan and is usually sufficient.

It must not be imagined that we can gauge the effect of any operation accurately enough to exactly restore a normal balance, though we may hit it fortuitously, but by care we can so nearly restore the balance that it can be reëstablished and maintained by the fusion powers. For this reason it is highly important that after any operation the full refractive correction be continually worn and that more or less exercise of the fusion sense after the method of Worth be practised.

Divergent squints are comparatively rare in young people, as they are commonly the result of convergence insufficiency from overwork and do not appear till later in life. The muscular weakness is generally shared by both eyes, typical tropometer record being:—

R.E. 40 x 55
L.E. 40 x 55.

It is very much more difficult to treat these than convergent squints and in the majority of cases tenotomy of one or both externi will be necessary and in many others an additional advancement of one or both interni. In some cases, however, the tropometer will indicate that the abnormality is confined to one eye and in such the operative treatment should, if possible, be limited to this one also.

Vertical squints are, for the most part, congenital anomalies, due either to some asymmetrical development of the skull or defect in the origin or insertion of some of the elevators or depressors of the eye. The individual is often able to compensate for his defect by tilting his head till his eyes are on a level, but in many cases where there is no attempt at compensation and fusion, the defect is not a conspicuous one. We have seen in latent squint how slight are the powers of the eye to fuse vertical diplopia, and a slight vertical squint by destroying the possibility of fusion often makes manifest a convergent or divergent error which would have been easily overcome, if uncomplicated. Attempts at fusion of vertical diplopia being made through the third nerve often result in over-innervation of the interni or the ciliary muscle with resulting convergent squint.

Vertical defects are generally treated by tenotomy, preferably of a superior rectus. Vertical strabismus may be due to spasm of one or both inferior obliques. In looking to the left and upward the right eye shoots up more than the left, while in looking to the right the left shoots up. This is sometimes a true concomitant strabismus but in many cases is monocular, the spasm of the oblique resulting from over-innervation necessitated by the weakness or paresis of the synergistic superior rectus of the other eye. The treatment is a tenotomy of the oblique through a skin incision at the lower inner orbital margin, where its tendon can be picked up. It may be necessary to exsect a bit to get sufficient effect, and in the concomitant cases operation on both eyes may be needed.

Operations on the vertical muscles should be done only as a last resort, since bad results are very frequent. It should always be remembered that these are the cases in which the use of permanent prisms is likely to be most effective, and they should always be tried.

The treatment of strabismus, when one eye is blind, or hopelessly amblyopic is somewhat different, since all we can hope to secure is a good cosmetic effect, binocular vision being out of the question. In young children, however, great pains must be taken to be certain of the hopelessness of the amblyopia by the continued use of bandage and atropin in the good eye. The refraction of the good eye should be carefully estimated and fully corrected, as, if the squint is the result of excessive accommodation, it will often disappear from this means alone.

There is no use in trying stereoscopic exercises or the amblyoscope since there is no possibility of developing binocular vision (and the same may be said of cases in adults which have been present since childhood, since the fusion faculty cannot usually be restored after the age of five or six years). Neither is there any haste about operation after the refraction of the good eye has been corrected since the squinting eye is already as amblyopic as possible and the cosmetic effect only is sought. I am of the opinion that this may just as well be deferred till the child is old enough to become self-conscious. By that time very often it can be corrected under local anæsthesia. Exact measurement of the rotation of the squinting eye is often difficult owing to the amblyopia present, but it is not important, for slight over- or under-correction cannot cause the subjective suffering of latent squint when one eye is blind. The good eye can and should be measured to see if there is any muscular abnormality there, but unless this is very marked, the amblyopic eye alone should be operated upon. Since cosmetic cure and not accurate restoration of balance is sought, the simpler the operation the better. Generally a partial or complete tenotomy of the overacting muscles will suffice and tenotomy has the advantage that it can be done even in children in a very brief time and under local anæsthesia.

Atropin immediately after operation causes an apparent increase in the effect of operation by lessening convergence. The final result is, however, diminished because the cut muscle does not retract so far and therefore has more power.

Tests of Cure.—When one eye is amblyopic, the only possible object of operation is cosmetic effect, but when good vision is present in both, we are not entitled to consider a case cured absolutely unless the eyes can pass all the tests of muscular balance of the normal eyes. Such cures are very rare indeed. One has every reason to be satisfied, if he has so nearly restored the balance of the muscles that the patient by aid of his fusion power can maintain binocular single vision for far and near points without obvious discomfort.

A very convenient way of testing this at the near point is to have the patient with both eyes read some Jaeger type at the ordinary distance while the physician interposes a pencil midway between the eyes and the page. If the patient is fixing the same letters with both eyes, he can read without interruption, but if he is using only one eye, the pencil cuts off a portion of the text which he cannot see without moving his head.

CHAPTER XIV.

OCULAR PARALYSIS.

We have seen that the movements of the eye are regulated by centres of different rank. In the first place there are the centres situated in the floor of the fourth ventricle which govern the action of each individual muscle through the oculomotor nerves. A lesion here might involve one nucleus and so cause the paralysis of a single muscle or several. A lesion lower down, involving the trunk of the third nerve, would paralyze the action of all the muscles supplied by that nerve, while peripheral lesions still further down might again affect only branches of the nerve and so paralyze only single muscles.

The second group presides over the involuntary function of binocular vision, the so-called fusion centres. They are involuntary and their localization is not very clear. The third group is located in the cerebral cortex, and governs the voluntary motions of the eyes up and down, to the right and left, etc. Lesions involving one of the last named centres do not cause a direct paralysis of any muscle, but only prevent the coördination of the two eyes or their conjugate motion in some one direction. For instance, a lesion affecting the fusion centre might cause a paralysis of convergence, apparently affecting both interni, but neither one is paralyzed, as can be proven by their turning normally to the right or left. A cortical lesion might entirely prevent the turning of the eyes to the right, but the right externus and left internus are not individually paralyzed, because the eyes can still converge and diverge under prism tests.

Motor Paralysis involves the absolute inability of one or more muscles to react to innervation from any source. It may be either partial or complete and, when recent, is characterized by several distinct symptoms.

Limitation of motion is the most noticeable, the rotation of the eye toward the paralyzed muscle being diminished or entirely abrogated. For instance, in complete paralysis of the right internus there would be an absolute inability to turn the eye to the left beyond the mid-line. Such a defect would be very noticeable, but if the paralysis were incomplete, the defect of motility might be so slight as only to be made out with the perimeter or tropometer. If we have the patient look at a pencil directly in front, the left eye will converge, but the right eye cannot. If we carry the pencil to the right out of the field of the paralyzed muscle, the eyes resume their normal relation to each other, while if we carry it to the left, the right eye lags more and more behind and a divergent squint becomes more and more apparent. This distinguishes paralytic squint from concomitant which is present in all directions and is unchanging in degree.

Primary and Secondary Deviations.—If we have the patient fix a pencil directly in front and interpose a screen before the paralyzed eye, it will assume the position of rest behind the screen and turn slightly outward. This deviation in the paralyzed eye is the primary deviation. If we now change the screen to a position in front of the sound eye and compel the paralyzed eye to fix, it will do so, if at all, by an extreme innervation of the weak muscle. But since convergence is an associated function of the eyes, an equal stimulation is sent from the convergence centre to the internus of the other eye, and this being perfectly healthy undergoes an extreme contraction. Therefore the secondary deviation of the sound eye behind the screen is much greater than that of the paralyzed eye. If the impulse comes from the centre governing conjugate motion to the left as when we carry the pencil to the left of the mid-line, the over-innervation will go to the left externus and the left eye will deviate outward behind the screen. This again distinguishes paralytic from concomitant strabismus in which the primary and secondary deviations are always equal.

False Projection.—When the healthy eye is closed, the patient does not see things in their normal position. For instance, in the case supposed if he be directed to point quickly to some object a little to the left, he will invariably point too far to the left, and if told to walk toward it he will go in a zig-zag course, starting out too far to the left, correcting his mistake and then making it again. The object is not correctly localized, because the patient is not aware of the actual position of his own eye which is turned slightly outward. The image of an object straight in front then falls to the outer side of the macula and therefore seems to the patient to be located to his left. If the object be carried to his left, he makes an effort to follow it with the paralyzed muscle. From the amount of energy expended he feels as though he had rotated his eye far to the left and was looking in that direction, while in reality its position is unchanged. In time he learns to form a new set of judgments and is no longer troubled by false projection.

Diplopia is present when both eyes are used together and turned in the direction of the paralyzed muscle. For instance in the case supposed, if a candle somewhat to the left be regarded with both eyes, its image will be at the macula of the healthy eye, but in the paralyzed eye it will fall somewhat to the outer side of the macula and will therefore seem to the patient to be further to the left than it really is. He, therefore, sees a sharp distinct candle in its normal position and to the left of this another which, being non-macular, is not so distinct. The further the candle is carried to the left, the further from the macula is the second image formed and the greater the diplopia, while if it is carried to the right, the diplopia diminishes, and when out of the field of the paralyzed muscle, disappears entirely. If the paralysis were incomplete, the diplopia and strabismus would not show unless the object were carried considerably to the left.

From the position of the eyes in which strabismus and diplopia first appear, from the relation of the images to each other and their behavior when the eyes are moved in different directions, we diagnosticate which of the ocular muscles are paralyzed and how extensively.

Vertigo.—When the paralyzed eye regards an object slightly to the left of the mid-line, it is as previously explained falsely localized to the left, and the more it is stimulated to turn in this direction the greater the projection to the left. Consequently all outside objects appear to move with constantly increasing velocity to the left and this causes vertigo which the patient soon learns to abolish by covering the paralyzed eye or by maintaining an oblique position of the head. Our patient by carrying his head turned toward the left does not have to use his right internus except in looking to the extreme left and therefore has no diplopia. Many of these positions of the head are characteristic of certain paralyses.

Old paralyses have many modifications of these symptoms. The patient gradually learns by experience to avoid his false projection and again localize objects correctly. He gradually learns to suppress the troublesome image found in the squinting eye and no longer complains of diplopia or vertigo. Contraction takes place in the antagonist of the paralyzed muscle. For instance, in our patient a contraction in the right externus gradually occurs so that the eye turns more and more to the right. The squint becomes more and more extensive and finally exists not only in the field of the paralyzed muscle, but in the entire field of rotation. Such cases get to resemble very closely cases of concomitant squint and the contraction or hypertrophy may remain after the paralysis itself has been cured.

Varieties of Paralysis.—One single muscle may be affected or several. When only one, it is apt to be the externus or the superior oblique which have an individual nerve supply. Paralysis involving several muscles is most apt to be due to lesions involving the motor oculi in some or all of its branches. Complete oculomotor paralysis is characterized by complete inability to raise the lid, to turn the eye in or up or down. Since the externus and superior oblique are not affected, the eye is rotated outward and somewhat downward by their action.

The iris and ciliary muscles are paralyzed also so that the pupil is widely dilated and immobile, and the accommodation paralyzed. Sometimes the eye protrudes slightly because of the relaxation of so many of the extrinsic muscles.

Sometimes all the muscles of one or both eyes are paralyzed (*Ophthalmoplegia totalis*). Again, all the extrinsic muscles of one or both eyes are involved, the iris and ciliary muscles escaping (*Ophthalmoplegia externa*).

Conversely sometimes the iris and ciliary muscles are paralyzed alone (*Ophthalmoplegia interna*). This may occur from involvement of the nuclei for the pupil and accommodation, the other nuclei in the brain escaping, or from peripheral causes like the use of atropin.

Etiology.—The lesions causing paralysis, either inflammatory or degenerative, may be situated from the first in the nerve tissue, but they are much more commonly the result of disease in neighboring structures, such as growths, exudates or hæmorrhages which cause secondary inflammation or compression of the nerves. Syphilis is the most frequent cause of ocular paralysis, whether through periostitis, gummata, exudates or the vascular changes induced by it. Another disease which should never be forgotten is locomotor ataxia which is very often characterized in the early stages by paralysis which may be evanescent. Other less frequent causes are toxic conditions, such as lead poisoning, diabetes, disseminated sclerosis, or infections like tuberculosis. Paralyses are very often the result of injury to the skull whether orbital or central. Diphtheria occasionally produces paralysis of the iris and ciliary muscles, and there is a large group of peripheral paralyses which appear to be the result of exposure to cold and are hence called rheumatic. Many ocular lesions once considered rheumatic are now known to be due to focal infections from diseased teeth, tonsils, sinuses and the like.

Paralysis may be congenital, the most frequent form being that of the externus of one or both eyes. In congenital cases contracture of the antagonist does not take place and the deformity is only noticeable in movements toward the affected muscle. Paralysis or absence of one or both superior recti has been noted in cases of congenital ptosis.

Site of the Lesion.—Careful study of ocular paralysis offers one of the best means at our command for localizing central lesions.

The diagnosis of an *orbital paralysis* must be made from other symptoms indicating orbital disease. Most important are the history of recent traumatism, pain, evidences of periostitis or an orbital tumor which can be palpated, protrusion of the eyeball, hæmorrhage into the orbit, etc. Examination of the fundus would sometimes show a unilateral optic neuritis from pressure which, if it were further back, would affect both eyes.

Lesions at the *base of the brain* may be assumed with more or less certainty when a number of other cerebral nerves are involved gradually in the order of their position at the base. For instance an olfactory paralysis would argue a lesion in the anterior fossa of the skull. Next in order would come the optic nerve and a lesion in this position would be singular in that it would cause complete monolateral blindness without changes in the fundus, while if it were lower down it would cause optic neuritis, and if higher up above the chiasm would cause a hemiopia, affecting both eyes. Contiguous nerves would be affected in turn, including the ocular nerves. When the trigeminus is involved at the base of the brain, neuralgia is a symptom which is not observed when the lesion is higher up.

Fascicular Paralyses are due to lesions of the nerves between their nuclei and their emergence at the base of the brain. For instance, a lesion in the pedunculus cerebri would involve the motor oculi and also the pyramidal tract above the point of decussation and therefore cause an oculomotor paralysis with a paralysis of one of the extremities on the other side of the body. This deduction would be a certain one provided the iris and ciliary muscle escaped, for it would prove that the lesion was high up in the peduncle where these fibres are still widely separated from the rest of the oculomotor fibres. If the oculomotor fibres were all involved with a cross paralysis of an extremity, the lesion might conceivably be situated at the base and near enough to the peduncle to injure it.

Nuclear Paralyses are due to lesions affecting one or more of the nuclei on the floor of the fourth ventricle. They appear insidiously, first attacking one nucleus and spreading to others in order of their location and affecting one or both eyes.

In cases where all the eye muscles except the ciliary and pupillary sphincters are involved, the diagnosis can be made with reasonable certainty, since if the lesion were lower down and affected the trunk of the nerve, the paralysis would be complete. Nuclear paralyses are generally due to primary nerve degeneration, the most frequent cause being syphilis, but any disease which develops toxins such as diphtheria or toxic substances such as lead, alcohol and tobacco, may be factors. Tabes, disseminated sclerosis and progressive paralysis are not to be forgotten. Nuclear paralyses, which are generally multiple, may be single. This is especially apt to be the case in tabes, one of the evident symptoms of which is ocular paralysis which may be slight and temporary or permanent and progressive.

Diagnosis and Localization of Paralysis is sometimes absurdly simple, but often extremely complicated and difficult, especially when several muscles are involved. The chief complaint of a patient with a recent paralysis is the annoying diplopia, and we determine that it is binocular by its disappearing when either eye is covered. The next step is to discover which eye has the defective motion which may be done in several ways. For instance, if we are using a candle as a test object, the image in the non-paralyzed eye is formed at the macula and is sharp and distinct, while that in the non-fixing eye is extramacular and more or less hazy and possibly tipped. Patients commonly speak of this without being asked. Then we have them follow with the eyes the movement of a pencil in various directions, and if the paralysis is complete we shall find that one eye lags behind the other in one or more directions. If the right eye fails to turn in toward the nose, the internus must be at fault; if it lags behind when the gaze is directed upward and outward, the superior rectus; if upward and inward, the inferior oblique. We examine roughly in this way the action of each of the individual muscles, always bearing in mind their anatomy and the position of the eye in which each develops the greatest power. But in many cases the paralysis is not marked enough to be made out by such rough methods and we have to base our final diagnosis on the nature of the diplopia and its behavior in different directions of the gaze. Finally, we can obtain very valuable assistance from the measurement of the rotation by the tropometer.

As previously stated, the image in the paralyzed eye is fainter and seems to move faster. The distinction is sometimes hard to bring out while the patient looks straight ahead, but if the object is carried in the direction of the greatest diplopia the normal eye will retain its distinct image, while the other, being formed further and further from the macula, becomes indistinct and seems to move faster and faster. (In case of opacities or high refractive errors the image in the non-paralyzed eye might be the more indistinct). To facilitate the identification of the false image in further tests we can place a red glass over the eye. Suppose we find that the false image is in the right eye, if the lateral diplopia increases markedly when the patient attempts to follow the candle to the right, evidently the right externus must be at fault, while if it increases when the candle is carried to the left, the right internus is defective. If the vertical diplopia increases markedly when the gaze is directed upward, one of the elevators of the right eye must be paretic, either the superior rectus or inferior oblique. It is evident, bearing in mind the physiological action of each of these that if the superior rectus is the one, the diplopia will be greatest when the eye is turned outward so that its optic axis is in line with the course of the muscle and then rotated upward, while if the inferior oblique is the one at fault, the vertical diplopia will be greatest when the eye is turned as far in toward the nose as possible and then rotated upward in line with the course of the muscle.

If the vertical diplopia increases on looking downward, it must be because of the paralysis of one of the depressors of the right eye, either the inferior rectus or the superior oblique. If the inferior rectus, the vertical separation will be greatest when the eye is turned outward and downward, and if the superior oblique, when the eye is turned in and down.

Reference has been already made to the projection of images which fall on the retina of a squinting eye. If one eye fixes correctly while the other turns down, the image in the second eye falls below the macula of that eye, and is projected upward so that the image is not only fainter, but seems higher. If the squinting eye turns in, the image is formed to the inner side of the macula and being projected outward seems on the same outer side of the mid-line as the eye, from which it is called homonymous diplopia. If the eye turns out, the image forms to the outer side of the macula and being projected inward appears on the other side of the image of the sound eye (crossed diplopia). In other words, the image appears to be opposite to the direction of the visual line. If the image is up, the eye must be down; if the image is to the right, the eye must be directed too far to the left, and *vice versâ*. A homonymous diplopia always indicates a convergence of visual axes and, if very great, a paralysis of an externus. A cross diplopia always means a divergence, and if great, a paralyzed internus. Another very important fact to be noted is whether both images are erect or whether one tips and how much. All the muscles of the eye except the internus and externus, theoretically cause a certain amount of torsion or wheel motion of the eye, and a paralysis of any of them permits torsion by the others, with more or less tipping of the image in the paralyzed eye which will vary much with the direction of the gaze, according to the muscle involved. The oblique muscles have much more torsion function than the straight ones and where the tipping is extreme a paralysis of one of them is to be suspected. If the straight muscles alone are involved, the tipping is not so great, and very often cannot be distinguished at all.

If we cause the patient to look at a pencil held vertically in front of him, and study the double images, so long as they seem parallel we may practically exclude an oblique paralysis. If, however, one of them be distinctly out of plumb we can readily tell by interposing a card which eye has the tilted image, and if we tip the pencil till it seems vertical to the patient its direction must correspond to the position of what was the vertical meridian of the eye before the paralysis. If this meridian is now tipped outward, it must be due to an undue relaxation of the superior oblique, if inward, of the inferior oblique.

The same thing will be observed if a Maddox rod be placed before the eyes alternately with its axis horizontal. The sound eye will be conscious of a vertical band of light in looking at a candle flame while in the paralyzed one it will be slanting until the rod is rotated in the trial frame so as to lie at right angles to the true vertical meridian, when the line of light will again appear vertical. Knowing the position of the true vertical meridian, it is an easy matter to decide whether it has been tipped outward by paralysis of a superior or inward by that of an inferior. The following routine method of studying the diplopia will be helpful to the beginner. The ocular images are identified by placing the red glass invariably over the right eye, so that the red image always means to the observer the right and the white image the left eye. Instead of having the patient fix a distant light and get the various eye positions by turning his head, the student should face him, holding a small flash light for the patient to follow with his eyes. In this way he will get a clearer mental picture of the muscles called into play.

Let us suppose a paralysis of the right externus. In the primary position there may be a decided lateral diplopia or it may be very slight. When, however, we move the light to the right, the patient's right eye, trying to follow, lags behind and the red image, instead of being formed at the macula, falls on the inner half of the retina and gives the impression of being farther to the right than it really is.

But a paralysis of the left internus also causes a lateral diplopia, which also increases as the eyes are turned to the right. In this case, however, the left eye lags behind, the white image falls on the outer half of the left retina and seems further to the right than it really is. In either case the false image is to the right. To be sure the diplopia is in one case homonymous and in the other crossed, but this is a matter of academic interest only, the important point being that *a lateral diplopia, increasing as the eyes are turned to the right, indicates a paralysis of the*

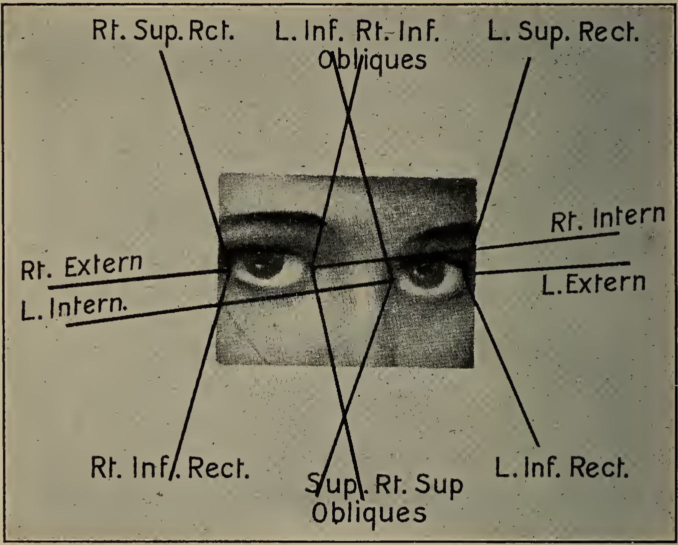


FIG. 101*a*.

right hand muscle of the eye having the right hand image. Similarly *a lateral diplopia increasing eyes left, always indicates a paralysis of the left hand muscle of the eye having the left hand image.*

The same principle can be applied to vertical diplopias. Let us suppose a paralysis of the right superior rectus. This will cause, in the primary position, a vertical diplopia which is theoretically crossed and with the false image slightly tipped. But we have already seen that if there was a preëxistent esophoria, the diplopia may be homonymous, while the tipping is seldom seen and may then be due to suggestion or to a preëxistent cyclophoria. From the diagnostic point they may be dismissed as interesting, but not important. If, however, we compel the patient to turn his eyes upward either by raising the light or tipping his head, the right eye lags in proportion to the amount of paralysis, the red image is formed on the lower half of the retina and the candle seems higher than it really is, while the further the eyes are turned upward the greater the vertical separation. The same reasoning holds true of the left elevators. Therefore *a vertical diplopia which increases markedly eyes up, indicates a paralysis of an elevator of the eye having the superior image. If the vertical separation is greatest when the eye is turned slightly outward the superior rectus is involved, if upward and inward the inferior oblique.*

If a depressor is paralyzed the affected eye lags behind when the light is carried downward, while the (red) image falling further and further above the macula seems to move rapidly downward. Therefore *a vertical diplopia increasing greatly eyes down, must be due to paralysis of a depressor of the eye having the lower image, the inferior rectus if the vertical separation is greatest down and out, the superior oblique if down and in.*

The same method can be applied to cases in which several muscles have been paralyzed simultaneously. In examining the lateral muscles, the amount of vertical diplopia should be entirely disregarded and *vice versâ,* while it must always be borne in mind that a diplopia which does not increase when the candle is carried in the direction of the suspected muscle is no indication of paralysis of that muscle.

The differential diagnosis is sometimes very difficult:—(1) when several muscles in one or both eyes are paralyzed, some completely and some incompletely; (2) when there is present a previous heterophoria of some sort. For instance a patient with an esophoria sustains a paresis of the superior rectus which destroys his fusion power exactly as though he were wearing a prism base down before that eye. Both eyes at once assume a position of rest, the paralyzed eye tending not only downward, but inward, and from the position of the double images we should assume a paralysis not only of the superior rectus, but a partial one of the externus as well; (3) when the vision in the paralyzed eye is so much better than its fellow that fixation is performed by it while the healthy eye is in a state of secondary deviation; (4) in old paralysis when secondary contractions have taken place or suppression of the false image has become a habit.

In all such cases the tropometer is a most valuable aid in the detection of the paralyzed muscle, the measurement of the defect, and will show from time to time progress or retrogression in the process.

In measuring the rotatory power of the interni and externi the head should be placed in the head rest in the usual or primary position (see page 239). In a complete external paralysis the eye cannot be brought quite to the mid-line and the patient must turn his head slightly to be able to fix the object spot at all. The outward rotation will be entirely absent while the inward will be unchanged. (It may be often apparently reduced because the start is made from a point within the field of the internus). In even a slight paralysis the rotation is very much more reduced than it is ever found in latent squint and by comparison with the rotation of the corresponding muscle in the other eye it is generally possible to distinguish paralytic from latent squint with ease. The same thing is true in paralysis of the interni. The tropometer may be used to measure the inferior and superior recti. The head should be placed in the instrument so that the right eye is turned slightly outward, and the upward and downward rotation carefully measured. The position of the head is now changed and the left measured in the same way, being careful not to change the horizontal plane of the eyes with the change of position. Any defects in the vertical rotations in these positions must be due to the straight muscles. It is impossible to measure separately the elevating and depressing power of the oblique muscles.

An exact record of the point and direction where a diplopia begins is important to enable us to say later whether the process has increased or improved. We place the patient at a perimeter and moving a candle or bright object along the arc in various directions having the patient follow with his eyes, and tell the instant the object appears double, we shall have an exact record of his ability to perform binocular fixation in various directions. A still better method consists in having the patient fix the centre of the tangent curtain (Fig. 109) with a red glass over his right eye, and then follow a small electric light in various directions. The points where diplopia begins and the position of the images in each of the principal meridians can be marked with chalk or colored pins and charted for record.

We place the patient's head in the primary position and have him fix a candle flame at a distance. If he sees double images, we place prisms before the squinting eye which shall bring the images together. This gives a record in prism degrees of the deviation.

The Treatment of ocular paralysis consists in a treatment of the original cause and also a symptomatic treatment to lessen the functional inconvenience. Syphilis which is so often the etiological factor should be combatted by very vigorous antisyphilitic treatment. It is to be remembered that these are almost invariably tertiary deposits calling for very large and increasing doses of iodide, and in cases where the etiology is uncertain this drug is far more likely to be of benefit than any other.

The tabetic paralyses, though probably of specific origin, are not benefited by antisyphilitic or any other treatment. Fortunately in many cases they are more or less evanescent. Paralyses due to hæmorrhage should be treated by rest and drugs which tend to reduce blood-pressure, such as aconite, and later by remedies which shall cause as much absorption of the clot as possible. The iodides in small doses meet both indications and can be continued for long periods.

The toxic paralyses are to be treated by iodide, the elimination of toxins being aided by purgatives, diaphoretics and diuretics, while the cases which seem to be rheumatic in their etiology do well under the administration of salicylates.

The chief sources of annoyance to the patient in any ocular paralysis are the diplopia, false projection and other subjective phenomena, which often make it not only impossible to work, but make mere existence a torment. To remedy this condition, we have two resources, to either blot out one image entirely by covering one eye or to bring them together by suitable prisms. Our choice depends on the circumstances of the individual case. Prisms are especially useful in paralysis of elevator or depressor muscles of one eye in which the diplopia is chiefly vertical and can generally be overcome by a comparatively weak glass. It should be just enough to abolish the diplopia when the eyes are in the position in which they are ordinarily used, and may be worn over the paralyzed eye or divided between the two. In this case the base of the prism would be over the paralyzed muscle in one eye, either up or down, and in the opposite direction in the other. Of course, when the eyes are rotated further in the direction of the paralyzed muscle, the diplopia reappears again, since prisms can only increase the field of binocular vision.

In paralysis of an externus a prism or prisms with the base out will serve to abolish the diplopia at all distances except when the eyes are turned toward the paralyzed side. In internus paralysis, on the other hand, the diplopia is greater and greater as the object is nearer the eye and a very heavy prism would be required with the additional disadvantage that the one which abolished diplopia at a distance would be useless for near work and *vice versâ.*

In complicated paralyses or those where very heavy prisms would be required, we shall do much better by our patient if we abolish the diplopia entirely by excluding the paralyzed eye by a pad or better still by a ground glass lens. Another procedure is to place over the paralyzed eye a prism which shall displace the false image so far up or down that it is very easily suppressed. This has the advantage of being much less conspicuous than the other methods. After a time without treatment of any sort the patient either learns to suppress the false image or to carry his head in such a position that the diplopia is abolished.

Operative procedures should be adopted only with the greatest caution and nothing should be undertaken till the paralysis has certainly reached its maximum of progression or of improvement after several months. Tenotomy is ordinarily not indicated except in old paralyses where contracture of the antagonist must be overcome, since the object to be attained is an increased rotation in the field of the paralyzed muscle. This is to be attained only by advancement of the muscle, and since it does not affect the paralysis but only places the muscle in a more favorable mechanical position for using any power it has left, it should be considered with great care.

In paralysis of a right elevator an advancement of the superior rectus would place the eye on the same level as its fellow in the primary position. There would still be diplopia when the gaze was directed far upward, but it would not be troublesome in any ordinary occupation.

In paralysis of an externus an advancement would abolish the diplopia straight in front, and it would remain only when the gaze was directed toward the defective side. A tenotomy of the internus would not be indicated unless it was in a state of secondary contracture, since it would have no effect on the distance diplopia and would also lessen the convergence power of the eyes for near work.

Complete paralysis of an internus is not ordinarily benefited by any operation. An advancement sufficient to abolish the X diplopia for distance would be insufficient to help that at the near point, while if strong enough to accomplish the latter it would overcorrect the former. Attempts are made from time to time in paralysis of the oblique muscles to make the straight ones assume their functions. For instance, in a paralysis of the right superior oblique which rotates the eye outward and downward and intorts it, the insertion of the inferior rectus can be advanced outward and upward. In this position it depresses the eye and turns it out, while the intorsion can be managed by cutting the lower fibres of the internus so that its traction is chiefly on the upper half of the eyeball. Such operations are too problematical in their results to be recommended.

Paralysis of Associated Movements.—In all these cases there is inability to move both eyes together in a given way, but without any direct paralysis of any ocular muscle. The lesion must therefore be situated higher up than the nuclei of the ocular nerves, though as yet the centres for these different associated movements have not been accurately localized.

Paralysis of Convergence.—When complete, there is absolute loss of power to converge the eyes beyond the midline in fixing a near object. At a distance there is a slight × diplopia which is more and more marked as the object of fixation is brought nearer. There is, however, no paralysis of either internus since measurement by the tropometer or perimeter will show that they exert their full power in rotating the eyes to the right and left, but simply do not receive any stimulation from the higher centres when convergence is attempted. These cases are often confused with convergence insufficiency, but the distinction is a clear one. Paralysis of convergence develops suddenly with great subjective discomfort because of diplopia and dizziness, false projection. etc. The convergence power is wanting entirely, the patient cannot overcome even a weak prism and the diplopia is a constant one, the images being always nearly the same distance apart at a given distance. In simple insufficiency the development is so gradual that the patient seldom complains of diplopia. He can often overcome weak prisms and the amount of diplopia is not constant at all, as after a rest the diplopia may disappear and the prism power increase markedly only to diminish again with fatigue. The great point in the differential diagnosis is careful measurement of the rotation of each eye by the tropometer. (Inward rotation cannot be measured accurately by the perimeter). If the abduction and adduction are of normal proportions, the diagnosis is established. If the adduction is reduced, the diagnosis is at least open to suspicion.

Paralysis of Divergence begins with a sudden homonymous diplopia, greatest at a distance and becoming regularly less as the object of regard is brought nearer till finally close at hand it disappears. It ordinarily diminishes, or at least does not increase when the light is carried to either side and the patient can maintain single vision much further when the light is carried away from the eyes than when it is approached. It is a constant one, not being capable of diminution through any effort of the patient after rest as in esophoria. Finally there is no limitation of the outward, nor increase in the inward rotation of either eye as measured by the tropometer, though this limitation would probably appear secondarily in old paralyses.

Conjugate Paralyses.—These are paralyses of certain voluntary motions of both eyes together to the right or left or up or down without any direct involvement of the ocular muscles themselves. They must therefore be caused by lesions in the motor areas of the brain. The cortical centre for the rotation of both eyes to the right lies in the left hemisphere, the innervation proceeding to the nuclei of the right externus and left internus. Any lesion affecting this cortical centre would prevent the rotation to the right, but would not prevent these muscles responding to innervation from any other source, as in convergence and divergence. In the case supposed the eyes cannot be carried together beyond the mid-line by any effort and the position of rest is with the eyes deviated toward the left. In other words, they look toward the lesion. These muscles themselves are not paralyzed, because the patient has no diplopia, and when the muscles are stimulated from the fusion centres, each can overcome the usual prisms showing that neither convergence nor divergence is impaired. The rotation of the eyes as measured by the tropometer is markedly affected, that of the rotators to the right being abolished or greatly reduced, and that of the rotators to the left somewhat increased. A lesion on the other side of the brain will cause a similar paralysis of left lateral rotation and similarly the ability to elevate or depress both eyes may be impaired. The localization of the lesion in these cases is not always simple. Sometimes it occurs in cerebral hemorrhage as a so-called distant symptom through the temporary suspension of function of the whole side of the brain, though the centre for rotation is not involved. There is reason to suppose that the impulse for lateral rotation travels through the nucleus of the abducens from which a few fibres go to the internal rectus of the opposite side. A destructive lesion of a portion of the nucleus might cause a conjugate paralysis, but if at all extensive would paralyze the externus itself, as shown by inability to overcome prisms base in, in that eye. The same conjugate paralysis may also be caused by lesion in the pons in both these cases on the same side as the paralysis, that is, the eyes look away from the lesion.

Paralysis of upward and downward motion of both eyes is said to be caused by a lesion in the quadrigeminal region.

The General Treatment of Associated Paralysis does not differ from that of actual muscular paralysis depending on a careful study of the probable cause and course. Conjugate paralysis, when dependent on the suspension of function of a whole hemisphere by cerebral hemorrhage, which does not actually involve the associated centre, is likely to be recovered from. In conjugate paralysis there is no diplopia, but the patient simply complains of inability to use his eyes in front and on one side and soon learns to compensate by turning his entire head in that direction. His comfort in the primary position can often be greatly increased by the use of equal prisms over each eye with the base in the direction of defective motion.

The best treatment for convergence paralysis is an exclusion pad and monocular vision. In divergence paralysis it would seem that advancement of both externi with, if necessary, tenotomy of the interni would abolish the diplopia at all distances, but if the muscles themselves are of normal size, the result would be an insufficiency of convergence which would cause much more suffering than the exclusion of one eye by a pad.

CHAPTER XV.

COLOR-BLINDNESS.

We have seen that when vibrations are set up in the ether, they are transmitted in the form of waves of different lengths which are perceptible to us according to their length and character, as heat, sound, light, etc. But those which excite in us the sensation of light are not all of the same length, and, if passed through a prism as in the spectroscope, are bent more or less according to their length, so that when they are intercepted on a screen, they appear in the colored bands of the spectrum. The shortest waves are refracted most and seen by themselves give us the sensation of violet. As the waves become longer, we get a gradual transition to indigo, then to blue, then green, yellow, orange, and finally the longest give us the sensation of red. Waves longer than these are not manifested as light, but take the form of heat, while the shorter ones which are also not perceptible to our coarse senses, cause chemical changes as in photography. If these colors are again gathered together by appropriate means, they give us the sensation of white light.

Some substances have the power to reflect and absorb waves of certain lengths and so give us the sensation of color. For instance, a piece of red paper reflects the long rays and absorbs the short ones, and so gives us the sensation of red. A red glass transmits the red rays and absorbs all the others. When a substance reflects all the rays it gives us the sensation of white, and when it absorbs all the rays, that of black. The character of a color depends on these factors, first the wave length of the rays which determines the hue, second the amount of colored light falling on the retina in a given time which determines the intensity, and third the amount of white light mixed with the color which determines the so-called saturation as expressed by the words pale, deep or rich. We have seen that all the colors of the spectrum when united together make white again, but white may also be produced by mixing only two colors if properly selected, and any two colors which together make white are known as *complementary colors*, of which the following with their respective wave lengths are examples:—

Red λ 656	and	Blue Green	λ 492
Orange λ 608	and	Blue	λ 490
Yellow λ 574	and	Blue	λ 482
Yellow λ 564	and	Indigo	λ 462
Greenish Yellow λ 564	and	Violet	λ 433

Every color in the red end of the spectrum has a complementary color in the blue end, while the complementary colors for the middle of the spectrum are composed by a mixture of colors from the ends. The complementary color for green, for instance, is purple composed of a suitable mixture of red and blue, as shown in the diagram. Naturally, the white formed by the mixture of two colors is not so intense as that in which all the colors are combined.

The results of experiments made by the mixture of various *pigments* do not correspond to those made with decomposed white light. The reason for this is that no pigments are absolutely "pure," but possess color, because when light falls upon them they absorb some rays while they reflect others. Thus gamboge reflects the yellow rays chiefly, but also many of the green, at the same time absorbing the blue and some of the red. Thus it is yellow, but not the pure yellow of the spectrum. Indigo, on the other hand, absorbs the red and yellow and reflects the blue and some green rays. When gamboge and indigo are mixed, the result is green, because the first absorbs the blue, while the last absorbs the yellow and red, while both reflect the green. If, however, we take a pure spectral color which excites in us the same sensation as gamboge and mix it with another which corresponds to indigo, the resulting impres-

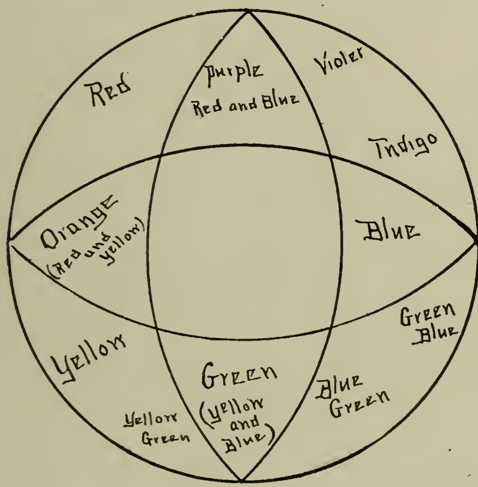


FIG. 102.

sion is that of white instead of green, which goes to show that mixtures of pigment may produce very different effects from mixtures of the *sensations* produced by those pigments separately.

In dealing objectively with pigments, we find that by combinations of the three so-called *primary* colors red, blue and yellow and their derivatives, we can produce all the other colors. On the other hand, in dealing with the *subjective* sensations produced by decomposed light or comparatively pure pigments, we find that by combining in various proportions the *sensations* produced by red, blue and green (instead of yellow) we can not only produce white, but by varying the proportion and intensity of the three, produce the sensation of any other color of the spectrum. These results show that our recognized *color sensations* may be reduced to three, that is to say, our vision is trichromic as based on variations of three primary color sensations. When, however, we begin to investigate the physiological processes by which we apprehend color, we

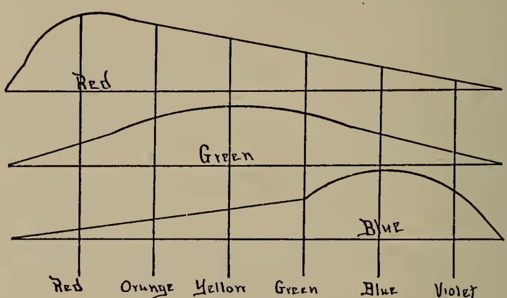


FIG. 103.

are confronted by several rival theories: the chief being those of Young-Helmholtz and of Hering. We cannot go into these theories deeply, but suffice it to say that most facts can be explained by both, but there are a number that seem consistent with neither. According to the first theory there are three sets of fibres in the retina, all of which are excited by every color, but with different intensities. One of these is affected most strongly by the long waves and gives the sensation of red; another set which responds most strongly to blue waves and a third to the green. A combination of waves which stimulates more than one set of fibres would give a sensation of composite color according to the amount of stimulation of each as shown in the diagram, which makes no pretense, however, of showing the exact proportions of each which cause any sensation.

For instance, a combination which stimulates the red fibres strongly and the green and blue in proper proportions, would give us a sensation of orange, and so on through the spectrum. A combination which excites all the fibres would give the sensation of white light and the absence of stimulation would be black.

If all of these fibres are wanting or not capable of stimulation, the individual is totally color-blind. If he looks at a colored object, he is only conscious of the white light which is present in varying degrees in every color, and since the white is faint the object presents instead of color various shades of gray as in an engraving. More commonly only one set of fibres is wanting, for instance the red. When such a person looks at a red object, his red fibres are not stimulated and he is conscious only of the stimulation of the green fibres and to a slight extent of the violet, which are combined in our sensation of red. A red object makes therefore on him the same impression as a green one, but he can commonly distinguish between the two by the difference in brilliancy. The red object looks green, but since the green stimulation is slight the sensation is a feeble one and the object looks dark, while a green object which stimulates the fibres normally is brilliant in color. In the same way there are persons in whom other groups of fibres are absent or under-developed and they are green-blind or violet-blind.

The other theory of color perception is that of Hering who supposes three distinct substances in the retina which undergo metabolic changes when exposed to light of various wave lengths. The first is a red-green visual substance which, so long as its metabolism is normal, gives us no sensation, but when katabolic changes increase causes a sensation of red, and when metabolic changes predominate that of green. In the same way there is a yellow-blue visual substance which furnishes through katabolic changes a blue and through anabolic a yellow sensation. The third substance is a white-black which governs our perceptions of white and black in a similar way. The two members of each pair are therefore not only complementary, but antagonistic. The white-black substance is influenced more or less by waves of all lengths, but the others are differently influenced by differing wave lengths and by combination of sensations from the colors of the spectrum. A person lacking one or more visual substances entirely or in part would be unable to distinguish red and green or yellow and blue, or possibly both. According to this theory also, our vision is trichromic, for the three pairs play the same part as the three primary sensations in the other, and all the results of the mixture of colors can be explained on either hypothesis.

What has been said so far pertains only to vision at the macula. As the colored object is moved so that the impression falls on the periphery of the retina, it becomes fainter and fainter and the extreme periphery may be said to be color-blind. The green sensation is lost first, next the red, next yellow, and blue last of all.

It might seem at first sight that color blindness, which deprives the eye of one-third of the total retinal stimulation, would reduce the visual acuity, but this does not seem to be the case, since the general vision of the color-blind seems to be as good as that of normal eyes; when within the range of colors which they can perceive, their acuity seems actually greater. Even in colors which they cannot see as such, they can distinguish differences of shade and tone dependent on the admixture of white which are beyond ordinary eyes.

This is to be accounted for on the theory of compensation for one defective faculty by compensatory keenness of another. It therefore entails no disadvantage on the subject beyond rendering him less fit for the duties of certain callings which depend largely on the keenness of the color sense, such for instance, as the painter, dyer, milliner, etc. Since in the railroad and nautical services it is customary to use colored signals, chiefly red and green, it is obvious that employees who cannot unfailingly distinguish between them must be a constant source of danger. Employment in these services is therefore in most countries only allowed to those who have passed the most careful tests of ability to distinguish colors. Such tests should be repeated at infrequent intervals, since while color blindness is generally congenital it may also be an acquired condition depending on changes in the retina and particularly on atrophy of the optic nerve. In this condition color blindness does not set in suddenly but gradually the perception for red and green diminishes, then for yellow and finally that for blue. In retinal diseases and chorioiditis on the other hand the perception of blue diminishes first. Testing of the color acuity may therefore be a very useful aid in the diagnosis between diminution of vision by refractive conditions in which it is unimpaired and disease of the percipient elements in which it is. (See chapter on "Field of Vision").

We have seen that few, if any, of the pigments, of colored papers, or glasses are pure colors and capable of exciting uncomplicated retinal sensations. Consequently for the scientific testing of the color sense the spectroscope is essential as the only means of giving us pure colors. By its aid we can determine whether any portion of the spectrum is wanting and by showing isolated portions of the spectrums we can determine the power to name them correctly and match them with other, similar colors. If the patient is affected with red-blindness, the red end of the spectrum excites no sensation in the fibres for the perception of red and consequently the spectrum is shortened at this end. The blue-green of the spectrum seems to him less deeply colored than the rest of the spectrum, giving rise to a

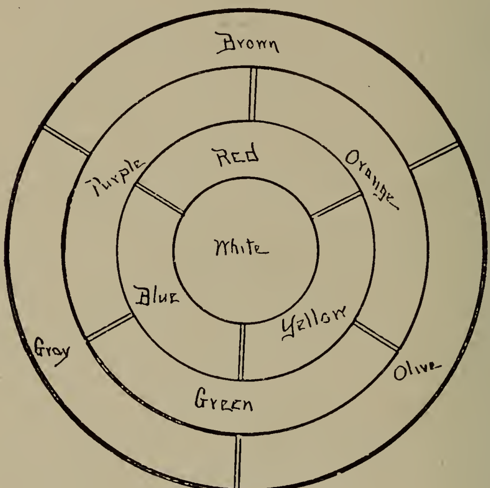


Fig. 104.

sensation like that of a feeble white or gray. This is spoken of as a "neutral band" and it is characteristic of red-blindness that the band occurs between the blue and the green. To the green-blind the spectrum is not shortened, but the neutral band falls in the green area, nearer the red end.

For practical purposes, however, we can approach sufficiently close to spectral colors with pigments, dyes or colored glass, to enable us to test the patient's color capacity and to determine in what respect it is defective. In all these tests it is important to bear in mind the composition of these synthetic colors in order to understand the sensation they give a patient who, being more or less color-blind, overlooks one or more of the constituent parts and so comes to a wrong conclusion regarding the color of the combination (Fig. 104).

There are several methods of ascertaining the ability of a patient to distinguish colors of which choice must be made according to the circumstances of the case, and great care taken neither to deceive one's self nor be deceived.

For instance, there are persons who have never been taught the names of colors and if simply required to name colors shown them, will make frequent mistakes on all but the simplest colors, while carefully tested by their ability to match colors without naming them will show their color sense to be normal. On the other hand there are many who have an obvious interest in deceiving the examiner, as in the examination of railway employees and persons interested in litigation for injuries sustained.

In testing the color sense of railroad employees it is only fair that tests should be made which are as much like those in the service as possible. For this purpose colored glass discs are used revolving in front of a lantern, of such size and brilliancy that they shall subtend the same angle and have approximately the same brilliancy as the signal lamps on the road. The Williams or Friedenberg test lanterns are good types. No attempt is necessarily made to have the patient name the colors shown, but only to recognize immediately their significance as indicating a clear track, danger, etc. The illumination should be so arranged that it can be increased or diminished by approaching or withdrawing the light or by the interposition of different shades of smoked or ground glass.

The commonest forms of color blindness are those in which red and green are confused and this would be particularly dangerous in railway employees, since these are the commonest colors employed in signals. A man may be color-blind and still be able to distinguish a red light from

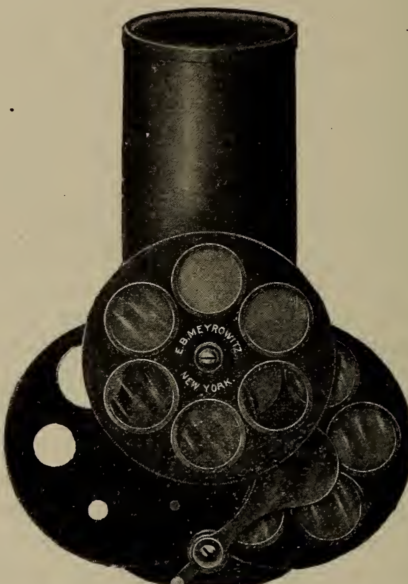


Fig. 105.

a green in the testing room. The lights do not seem to him to differ materially in color, but he distinguishes at once by their varying brilliancy. For instance to the red-blind the green signal is bright green, while the red one is the same color but very much darker, and he immediately identifies it as red simply from its darkness. Evidently, if we show him a green light and then, covering it for a second, reduce the illumination, the color-blind person will get the impression of red while normally he should still be conscious of green. If he is green-blind, the green light will appear simply as a differently illuminated red, and both these conditions are often approximated in the service when the brilliancy of signals is interfered with by atmospheric conditions. A man who makes no mistakes in a carefully conducted test of this kind would be competent enough for the ordinary duties of the service, but engineers and signalmen should be further tested in a different way to avoid any possibility of deceit. The patient is tested according to his ability to match colors and especially those which experience has proven to be most deceptive to the color-blind. This can be done by aid of one of the lantern devices which show two lights, one of which is left unchanged while the light of the other is colored or changed in intensity by the interposition of suitable glass discs, the patient being expected to call out rapidly whether the lights appear to him similar or not. The same thing can be tested by colored papers or powders, but the method in most general use is by the use of the colored wools of Holmgren. This has the advantage not only of being convenient, but from the very large assortment of different shades of the same color, it is possible not only to detect the presence or absence of color blindness, but slight differences in the acuteness of the color sense as well, which would be very important in certain occupations as in dyeing or dressmaking or chemistry. The test is ordinarily performed as follows, a good clear daylight being requisite. A skein of pure light green is placed by itself and the patient told to select from the rest four green skeins of darker shade which he must do rapidly and accurately. If he does this without hesitation and correctly, his color sense is probably normal, since, if he is either red- or green-blind, he is almost sure to pick out some reds which have an intensity similar to the green test skein. If he is accurate but slow, his color sense must be feeble, while if he makes mistakes even of the slightest, he probably has a defective color sense and

FIG. 106.

must be further tested to discover which color or colors are wanting. For this purpose we set aside for him to match a skein of purplish (rose) color (made by the mixture of red and blue. See Fig. 104). If he is red-blind, he is conscious only of the blue in the skein, while the red excites the same sensation as does green. Consequently he matches it with dark greens, dark blues or violets. If he is blue- or violet-blind—a very rare condition—he sees only the red elements in the skein and so matches it with reds or oranges according to its luminosity. If he is green-blind (green in dyes being composed of a mixture of blue and yellow), he is conscious of the blue element in the purple (mixture blue and red) and matches it with colors which contain blue like the blue-greens or grays (composed of mixtures of purple and green). The red element in the purple seems very bright to him and exciting the same sensation as green leads him to select also very light greens which contain an excess of yellow. If he matches colors of all kinds, selecting them simply by their intensity or the amount of white which each contains, he is totally color-blind.

Briefly stated, the rule is as follows:—

Test I. A pure light green, neither a yellow-green nor a blue-green, but intermediate: any selection of confusion colors indicates at least some color blindness. Slowness shows feeble color sense.

Test II. Purple skein (rose color):

1. He who is color-blind by the first test and who upon the second selects only purple matches, is not completely color-blind.

2. If he matches the test skein with only blue and violet, or one of them, he is completely red-blind.

3. If he matches it with only green and gray, or one of them, he is completely green-blind.

4. Purple, red and orange indicate violet-blindness.

Test III. A cherry-red skein of a deep, rich color: If he selects as matches for this red, green and brown, which to the normal eye appear darker than red, he is red-blind. If he selects shades which are lighter than red, he is green-blind.

For the quantitative testing of the color sense, small

Fig. 107.

discs of colored paper on a background of black satin have been devised which should be recognized at definite distances. The same effect can be obtained with the lanterns previously alluded to, the size of the disc of light being determined by diaphragms according to the distance, or by the ingenious instrument of Friedenberg which is constructed like a Loring ophthalmoscope except that the lenses are replaced by small colored discs and there is no mirror. These discs can be shown at will at the aperture, the size of the disc and the rapidity of exposure being under control of the physician.

Many other tests for color blindness have been proposed, most of which may be useful in doubtful cases, but are not in common use, and therefore have no place in a volume of this kind.

CHAPTER XVI.

THE FIELD OF VISION.

We have seen that in the expansion of the optic nerve which we call the retina, there is a small region, the macula, near the posterior pole of the eye which is much more finely organized than the rest, and is the only spot where sharp distinct vision is possible. Therefore, when we wish to see any object distinctly, we fix it or turn the eye in such a way that the image of the object of regard shall fall upon the macular region. This is known as central vision, and in our studies of visual acuity, refraction, accommodation, motility of the eye, and color perception, this has been our chief consideration. We shall now proceed to investigate peripheral vision which is the function of the remaining portion of the retina. Vision here is much less acute, and the further the image falls from the macula, the more indistinct it is as regards form. For perceptions of light and movement, however, the peripheral portions of the retina are said to be even more sensitive than the macular. This indirect vision is very important to us, since without it, even with the most distinct macular vision the external world would make the impression on us of being viewed through a double-barreled pea-shooter. We should see nothing without looking directly at it and should be constantly falling over objects just out of line of the central vision. As it is, images falling on the periphery, especially if they are in motion, attract our attention at once. We have already seen that objects which form an image on any portion of the retina are *projected* in a straight line through the nodal point of the eye, and we know at once that any image which falls on the right half of the retina must be situated to the left of the eye, and the further to the right the image, the further to the left the object. This gives us a correct idea of the position of external objects with relation to each other.

When we combine with this the knowledge of our own position in space, conferred by our sense of equilibrium, and the position of our eyes with regard to our bodies, which is conferred by the muscular sensations of the ocular muscles, we have a pretty exact estimate of the positions of objects in space, both with regard to ourselves and each other. Evidently this depends not only on correct retinal perception, but on correct cerebral perception and may be interfered with by abnormalities in either. Careful testing of the function of peripheral vision may therefore often be of great assistance in determining the existence and location of lesions in the central nervous system as well as those of the eye itself. All objects which make an impression on the retina, whether central or peripheral, are said to be in the field of vision, and the examination of this field must be made in each eye separately, the other being closed. The eye to be examined should be fixed on some object directly in front so that it shall remain in the same position throughout the examination and should be carefully observed from time to time to see that it does not depart from this position, otherwise the examination is of no value. All tests of the field of vision should be made, if possible, in a good clear daylight, with the patient's head in such a position that the test object shall have a good and uniform illumination. The simplest way of testing the field of vision is by using the fingers, a lead pencil or a bit of chalk as a test object. The patient is seated close to and facing the physician. He is directed to close his left eye and look directly at the left eye of the observer, who closes his right eye. He is thus in a position to make certain that the patient keeps his eye constantly in the primary position. The test object is then held at a point half way between the two and moved slowly up, down, in and out, the patient

From Peters's "Perimetry." Courtesy of Lea & Febiger

Fig. 108.

calling out when it disappears from view. If the object is kept constantly in a plane half way between the physician and patient, it should disappear from view of both at exactly the same time, always supposing that the field is normal. When the test is made in this way, there is an almost unavoidable tendency for the patient to follow with his eye instead of keeping it fixed and it is a much better plan to start the object at the periphery out of sight of both and have the patient call out the instant he is conscious of its presence, which should coincide with the consciousness of the physician. In this test he is not expected to wait till he can distinguish the form or the color of the object. The same maneuvre is then repeated with the left eye of the patient which fixes the now opened right eye of the physician. This method is capable of detecting large defects in the patient's field and is the only one available when the patient's eye is so defective that he cannot perceive small test objects. In some cases as in cataract we can arrive at valuable conclusions by using, instead of the hand, a lighted candle or a small electric light. A great disadvantage of this method is that while it helps to detect large defects, it affords us no means of recording either their exact extent or location, so that we cannot, at a later date, be certain whether the defect has changed its location or increased or diminished in size.

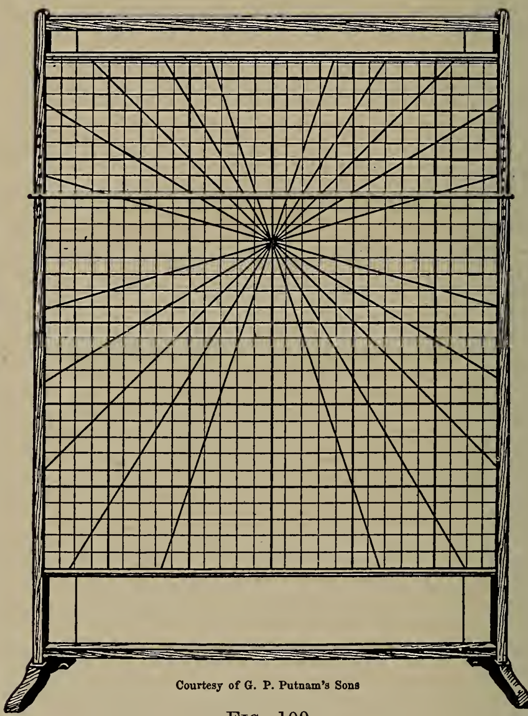
For a more acurate examination which can be recorded, a perimeter is essential. For all practical purposes this consists of a revolving metal half circle, numbered from the centre in degrees each way and so arranged that either eye can be placed at the centre of the curvature and fix the centre of the arc, the other being covered.

Care should be taken to have the patient seated with his head in the primary position, so that it is turned to neither side, nor up or down, and as in the other test, that he fixes the centre of the arc constantly. The test object should be white and of a definite size (generally one square centimetre). In default of this a hat pin with a white head makes an excellent test object. Let us suppose that we are testing the right eye. We arrange the arc so that it is horizontal, to test the field in the meridian of 180° and, beginning at the extreme temporal end of the arc, pass the object slowly toward the centre till the patient is conscious of its presence, which is commonly when it is between the 85th and 90th degrees. Noting this point, we continue along the arc toward the nasal side till the object disappears behind the patient's nose. Naturally this measurement depends somewhat on the shape of the nose, but should be approximately 60°. Even if the nose were removed, the field is not so extensive on the nasal side since the retina does not extend as far to the outward side of the fundus as to the inward.

If there have been any places along the arc where the test object has disappeared from view or is very dim, we note carefully the point of disappearance and emergence. For instance, a very small test object will disappear momentarily at a point between 10° and 20° to the temporal side which will correspond to the blind spot of Mariotte opposite the nerve head. Now we rotate the perimetric arc a quarter of a circle or in the axis of 45° and 225° and repeat the procedure, and again in the axes 90° and 270° and 135° and 315°. If we wish to be extremely accurate, we can test an indefinite number of meridians.

For purposes of record the whole can be plotted out on a circular chart in which the centre represents the point of fixation, the distances in degrees from this point are indicated by concentric circles and the different positions of the arc are marked in degrees on the circumference. (Of course, if both eyes fix the same object and are open, the fields of vision overlap each other, most objects directly in front coming in both, but a perimetric chart based on this would be confusing as it would not show in which eye the defective vision was.) One is much less likely to make errors of record if he uses a chart like the subjoined which shows both eyes together (Figs. 113-117).

We can now proceed to test the field of vision for color in exactly the same way, substituting for the white object green, red and blue objects, which correspond to the simple color perceptions of the retina. In these tests the patient



Courtesy of G. P. Putnam's Sons

FIG. 109.

should not call till he is conscious of the colors and not simply the motion of the object, and to be sure he actually does this it is better to alternate colors, marking the chart with appropriately colored pencils. Below is outlined a chart of the right eye showing the normal field for white and the colors. These measurements will all vary somewhat, depending on conditions present such as the size of the pupil which reduces the illumination, the brightness of the light, the size of the test object, the projection of the nose, cheek bones and eyebrows, and especially the drooping of the lids, so that in special cases it is often wise to record conditions as well as results.

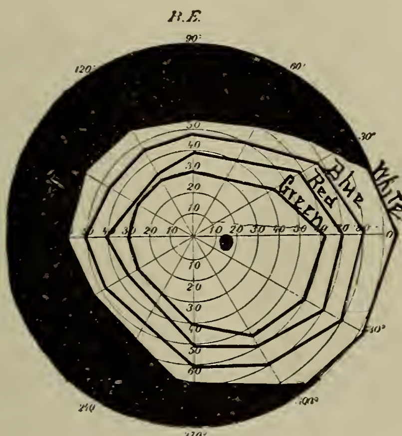


FIG. 110.

The perimeter is the best instrument to measure defects in the periphery but its arc is so close to the eye that small but important central defects which subtend a very small angle are easily overlooked and poorly recorded. For this reason the blackboard or better still the tangent curtain of Duane give much better tests, since the eye can be placed 30 or 60 inches from its centre with a corresponding increase in the scale of projection. The degrees marked on the curtain are the equivalents of those on the perimeter at the distance chosen and can be charted in the same way.

About 15° outward from the fixation point a small test object falls on the projection of the optic nerve and disappears in the so-called normal blind spot already spoken of. If the test object is moved in various directions in this

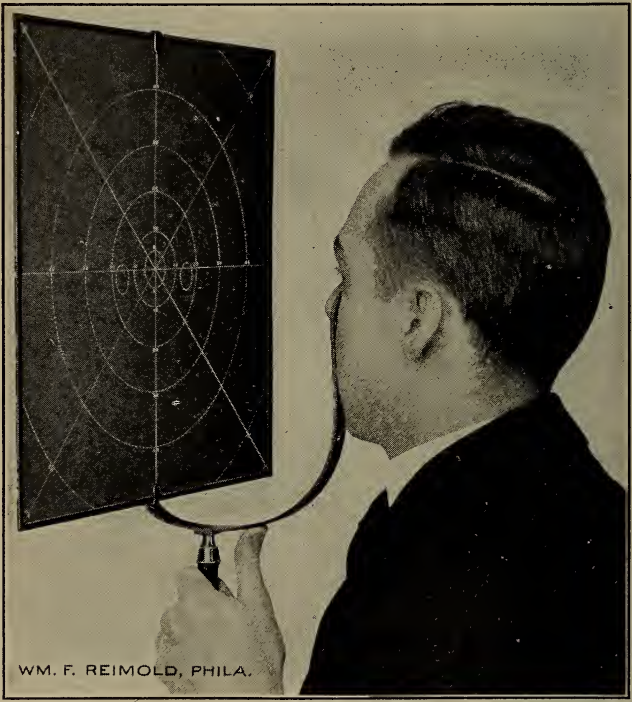


FIG. 111.

area while the patient calls out instantly when it comes into view, the spot can be mapped out and marked very accurately. It seems somewhat larger when the object is moved from the blind into the seeing field than in the reverse direction, but should be a vertical oval about 7° by 5°.

Enlargement of the blind spot is a very important fact. It may be due to such manifest causes as a myopic crescent but might also indicate such changes in the nerve as occur in early neuritis or optic atrophy or incipient glaucoma. On the other hand a normal blind spot would exclude many pathological conditions. Peters' campimeter is a very convenient instrument for rapidly investigating the size of the blind spots and central defects (Fig. 111).

For the discovery and localization of very small defects very small test objects are necessary—used with great care.

Changes in the field of vision are of two kinds: either the boundary of the field is concentrically or irregularly reduced, or isolated defects are found within the field which are called *scotomata.* The normal blind spot already alluded to is a case in point, but they may be present as the result of pathological changes. A *central scotoma* is one which involves the point of fixation and therefore greatly diminishes, if it does not destroy, the visual acuity, even though the limits of the field may not be reduced. The so-called *peripheral scotomata,* if they are distant from the point of fixation may never have attracted the patient's notice. The mapping of central scotomata is often very difficult because the eye being blind so far as its macular fibres are concerned, cannot see the fixation mark on the perimetric arc and is unable to keep any definite position.

In these cases the stereoscope may be used with a set of the cards devised by Haitz for the purpose. The known strength of the lenses and the distance of the cards makes it possible to have their scale correspond in degrees to that of the perimeter or tangent curtain. Each half of a card contains a heavily marked circle or cross which can be fused even when one eye has a central defect. With the poor eye thus fixed it is possible with the aid of very small test objects to map out and chart many small central scotomata which could otherwise only be suspected. This method also offers a very convenient way of mapping out

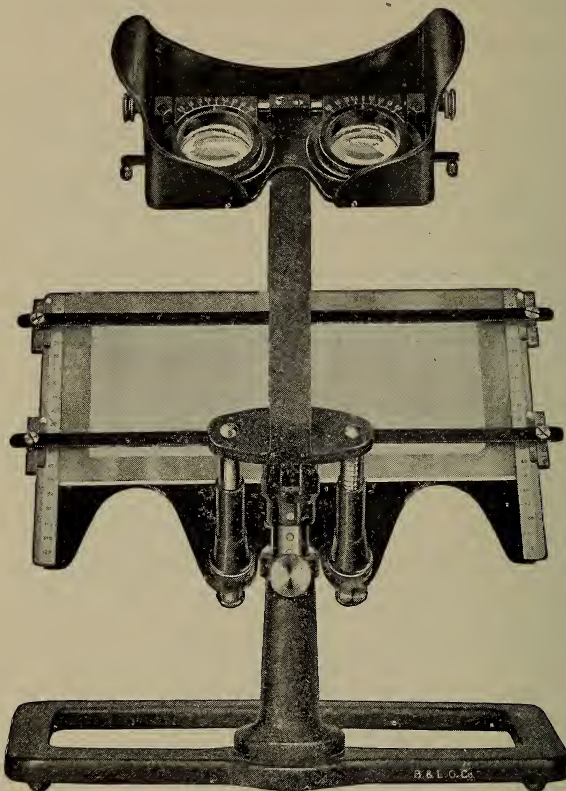


FIG. 112.

the normal blind spots whose average size is indicated on one of the cards. The patient should wear his distance glasses. This idea has been elaborated by Bausch and Lomb in their wide angle stereoscope (Fig. 112).

We secure the same end when we have the patient fix the white centre of the tangent curtain with both eyes open, but with a red glass before the fellow eye. If a green test object is used it is plainly visible to the uncovered eye but not to its fellow and if a scotoma is present it disappears or changes color just as though the other eye was occluded. If a green glass is used the test object should be red.

A *positive scotoma* is one which the patient can see as a spot or shadow. It is generally caused by opacities in the cornea, lens or vitreous, which coming between a healthy retina and the light, cast a shadow and so are perceived objectively. A *negative scotoma* is caused by an actual blind area in the retina from which the patient receives no impression. In other words, it is one which he cannot see objectively, though he may be conscious of its presence as a blank space in objects at which he looks, if it is near the fixation point. If we have a patient look at a uniform white surface like a plastered wall, we can sometimes make him conscious of the lack of illumination in this area, which then appears as a dark spot. For the time being the negative scotoma has become positive. If the retinal area is absolutely blind, we speak of the scotoma as *absolute,* while if the sensation is merely diminished, it is said to be *relative*. Relative scotomata are often only discovered by the use of very small test objects and tests with colors are very useful in discovering these relative scotomata, since colored objects fail to be perceived long before white ones, or become suddenly less bright.

The examination of the field with colored objects is therefore a very much more delicate test than with white, since it reveals deficiencies long before they could be detected by testing with white. This is especially useful in the atrophic changes in the optic nerve, in which color perception is diminished very early. The order in which the color sense is lost is also at times helpful. This diminution in the red and green perception is suggestive of changes in the optic nerve as in retrobulbar neuritis, while diminution of the blue sense is more characteristic of retinal and chorioidal disease.

L. E. R. E.

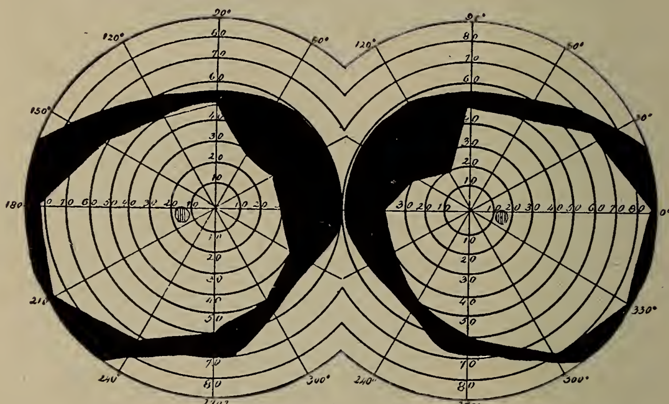


FIG. 113.

A careful examination of the field of vision is often of great diagnostic value, since many diseases, both intraocular and cerebral, are characterized by charts which are so constant as to be almost pathognomic.

Fig. 113. Beginning glaucoma simplex, where the central vision is perfectly normal, the tension not certainly elevated and the cupping of the disc not positive, the testing of the field is most helpful and there is no better means of keeping track of the progress of the disease. Blindness occurs from a pressure nerve atrophy, and long before there

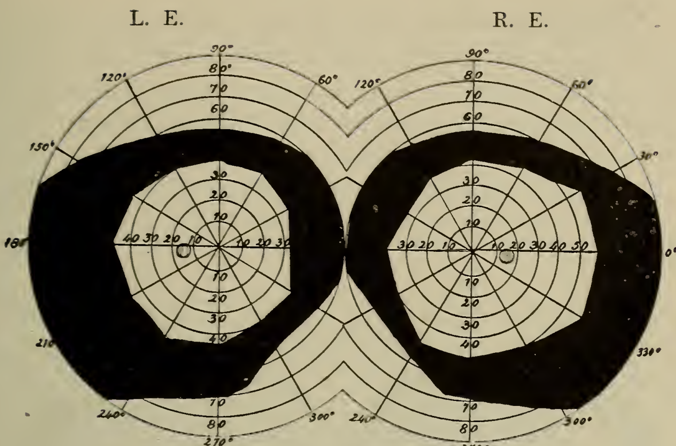


FIG. 114.

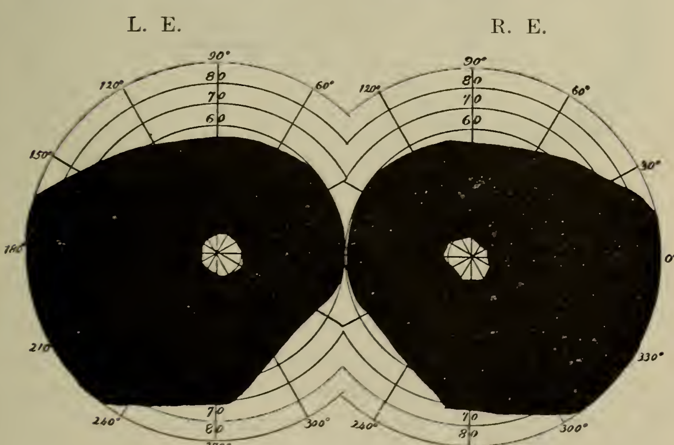


FIG. 115.

are any objective changes it is possible to demonstrate an enlargement of the blind spot, and later a characteristic notching of the field in the upper nasal quadrant.

This narrowing occurs long before there is any reduction in central vision and can be detected with a colored object long before it is evident with a white one. Reduction in the field for colors is always followed by reduction for white unless the progress is stopped.

Fig. 114. Simple atrophy, showing concentric reduc-

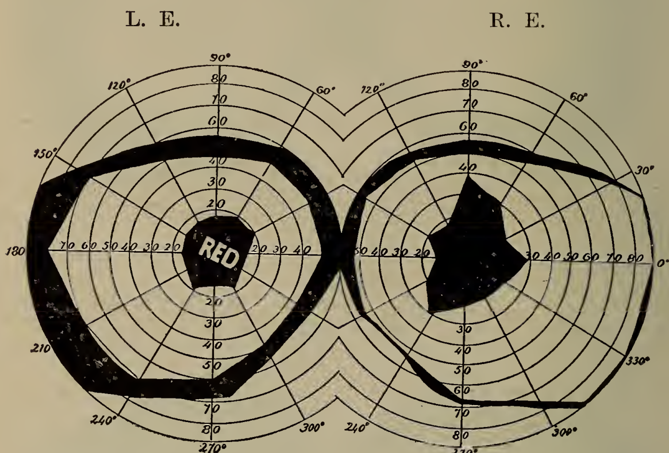


FIG. 116.

tion, central vision reduced, and the individual becoming color-blind early first for red, then green and last for blue.

Fig. 115. Retinitis pigmentosa. Central vision may be normal in good light. Reduction of field is concentric, begins very early and increases enormously when the illumination is slightly reduced. Blue color sense is lost first.

Fig. 116. Right eye shows central scotoma from macular chorioidal changes. Similar conditions at times result from high myopia, syphilis, and senile degeneration. The field outside is normal for white and colors, but is very

difficult to map out owing to inability of patient to fix and keep the eye still with a blind macula.

Left eye shows typical field in retrobulbar neuritis from tobacco, alcohol, etc. Central vision reduced and better in dim light. Field for white normal at first, but a central scotoma for red and green, and finally for white.

Fig. 117. Right eye shows sector deficiency due to

L. E. R. E.

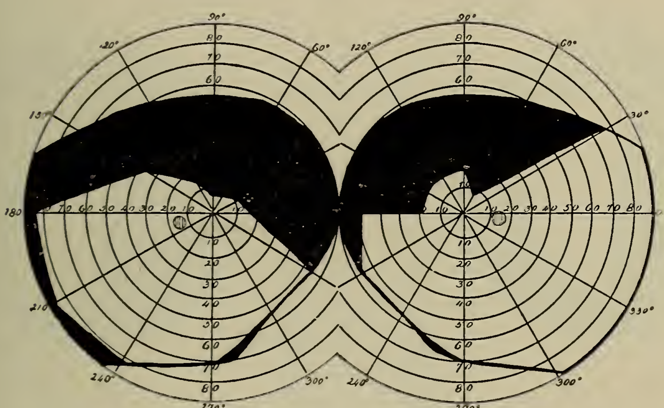


FIG. 117.

closure of inferior temporal artery. Left eye: the irregular reduction of superior part of field due to gradual separation of retina below. It can readily be seen how valuable such charts would be in estimating the progress of the processes as well as in the irregular fields caused by retinal hemorrhages, chorioiditis, etc.

Precedent to the formation of scotomata in chorioidal exudation, detachment of the retina, subretinal tumors, etc., there is very often present a marked distortion of the size and shape of external objects. The retina being pushed forward often irregularly, the image of an object, for instance a vertical line, no longer falls on the exact portion, from which the brain gets the sensation of verticality. The line, therefore, seems bent more or less, and if the retinal displacement is near the point of fixation, the distortion may be very great and annoying. Later on the retina loses its function and a scotoma develops in the area of distortion. Occasionally in detachment the retina will become

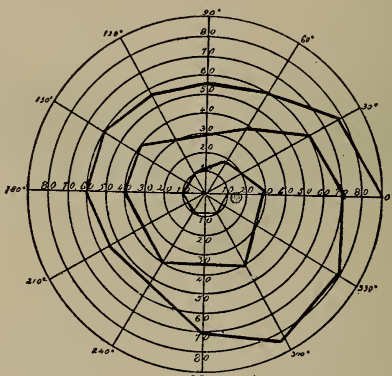


FIG. 118.

reattached and continue its function, and the individual with the aid of experience revises his judgment as to the meaning of retinal sensation from this area, and things no longer seem distorted (*Metamorphopsia*).

Fig. 118 shows a field often found in neurasthenia in which owing to fatigue of the retina when continually tested, the field keeps getting gradually and regularly smaller, recovering its function after a slight rest. Central vision may also show similar evidences of fatigue, but the relations between white and the colors is a constant one. In hysteria, on the other hand, the field is sometimes absurdly small without apparently interfering with orientation, and irregular and inconstant defects may be present.

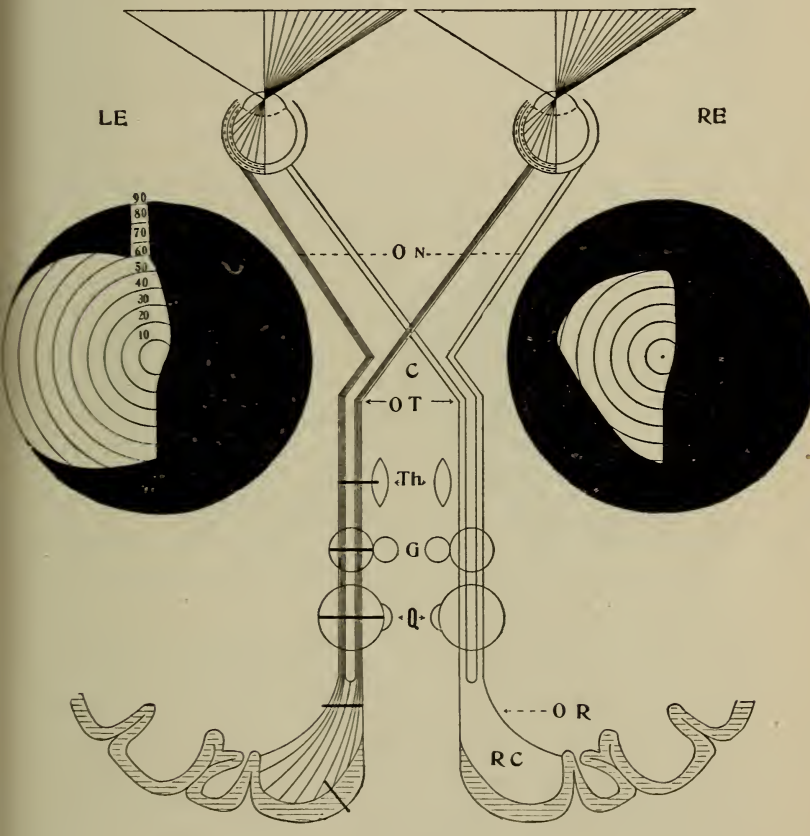


Fig. 119.

The color fields are often reversed and larger than the fields for white.

It can readily be seen that defects in the visual fields may not only be due to defects in one or both eyes, preventing retinal stimulation, but that even when peripheral parts are normal, there may be lesions in the conduction apparatus or others further back which prevent their reception by the brain itself. For this reason a careful study of the diagram which shows the paths of these impulses is advisable.

The retinal fibres unite to form the optic nerve which after penetrating the lamina cribrosa, passes through loose connective tissue to the apex of the orbit where it emerges through the optic foramen. This is really a short bony canal, which the nerve fits snugly so that at this point it is particularly subject to compression and constriction.

In the optic groove of the sphenoid the nerve unites with its fellow from the other side to form the chiasm. Here the optic tracts may be said to begin and pass backward, diverging as they go, toward the subcortical optic centres, the external geniculate bodies, the anterior corpora quadrigemina and optic thalami. The fibres of the optic tracts terminate in cortical ganglion cells in the optical area. These are the cells in which retinal stimuli are transformed into sensations.

The course of the fibres in the chiasm is also important. The fibres from the external half of each eyeball go back to the optic tracts on that side, while those from the inner half of each undergo a decussation in the chiasm and crossing over, join the tract on the other side. There are a few which pass from one tract to the other along the posterior part of the chiasm which do not reach the eyeballs at all. They are not, however, true optic nerve-fibres. The fibres which supply the lower part of the retina, are situated in the upper part of the chiasm, and *vice versâ*. Accordingly, all objects which are seen on the right of the field of vision, are perceived through the left half of each retina and the left hemisphere and *vice versâ.* Evidently any lesion affecting the optic nerve below the chiasm must find its effect in partial or complete blindness in that eye, the other not being involved at all, unless its nerve is also injured. Any lesion of one optic tract above the chiasm must result

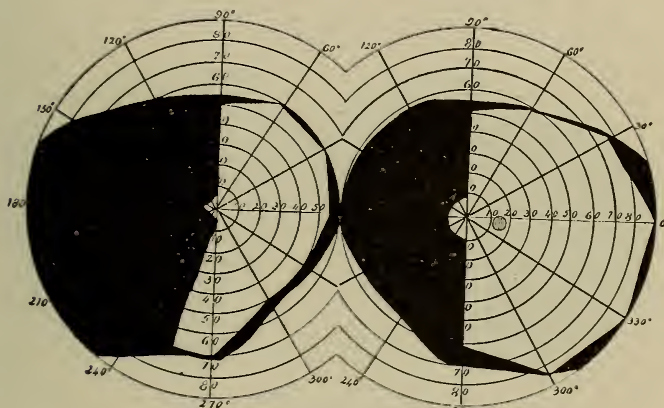


FIG. 120.

in a symmetrical blindness of the corresponding halves of each retina. This is known as *hemiopia* or *hemianopsia.* If the right tract is destroyed, the right half of each retina will not functionate, and the left half of the field of vision will be a blank. This hemiopia involving the same side of both eyes is known as *homonymous,* right or left as the case may be. We are still further aided in localizing the lesion by the reaction of the pupil. A few fibres are given off by each optic nerve which go to the nuclei of the third nerve and govern the reaction of the pupil to light. In such a case as we have supposed, if a bright light be thrown on the side of the retina and the pupil reacts normally, we know that the retina and the conducting fibres must be intact, at least as far back as these fibres. The lesion must be higher up and involve the perception centres themselves. If the pupil fails to react, the lesion must be low enough down to cut off these fibres. A lesion involving the chiasm

L. E. R. E.

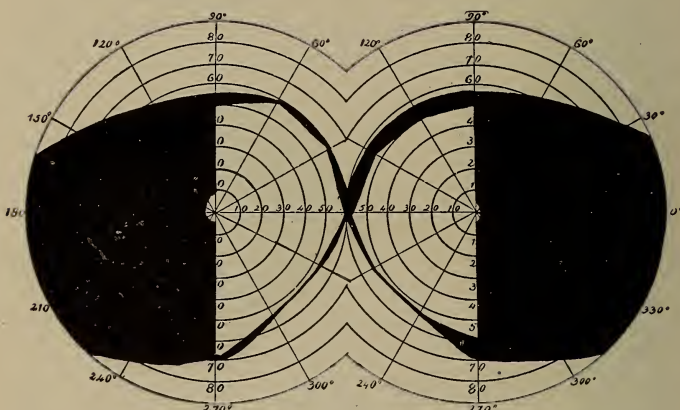


Fig. 121.

will destroy fibres going to the nasal side of each eye and cause the outer half of each field to be a blank. This is known as *bitemporal hemianopsia.* The line dividing the nasal from the temporal half of each retina as indicated in the fields of vision is generally nearly vertical and passing nearly through the point of fixation, but since the macula is supplied with a special bundle of fibres, the fixation point often escapes, the line ot demarkation curving out about it. Hemianopsia need not necessarily involve an entire half of each eye, since the lesion might destroy only a portion of the fibres, but it must necessarily be symmetrical. A central scotoma, of course, points to the involvement of the papillo-macular bundle of fibres. It can readily be seen how the study of the fields of vision may aid us in localizing brain lesions, especially when combined with the information derived from possible paralysis of the internal and external ocular muscles.

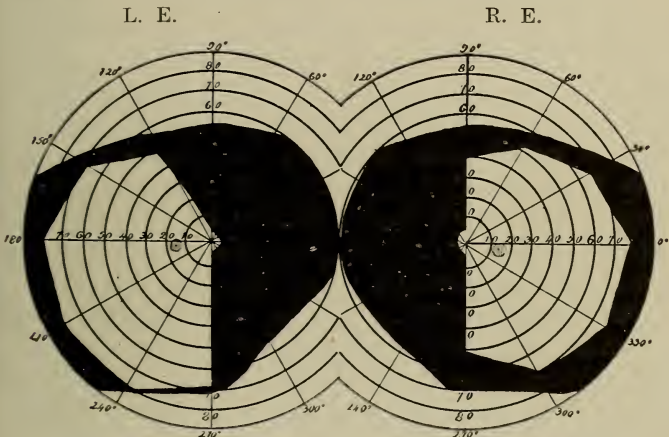


FIG. 122.

Fig. 120. Left homonymous hemianopsia with blindness of right half of each retina and lesion above chiasm on right side.

Fig. 121. Bi-temporal hemianopsia—inner half of each retina blind, lesion in chiasm, almost pathognomic of pituitary lesion, as in acromegaly.

Fig. 122. Binasal hemianopsia, caused by atheroma of blood-vessels pressing on right and left of chiasm, but not involving decussating fibres.

CHAPTER XVII.

THE RELATION OF FUNCTIONAL EYE DISEASES TO GENERAL MEDICINE.

The attention of physicians has been called from time to time to the connection of what we rather loosely call "eye strain" with various functional and even organic defects in other parts of the body. The extremists on one side argue that every error of refraction or motility, however small, is certain under conditions of continuous use to result in an abnormal expenditure of nerve and muscle energy; which even though it does not interfere with the keenness of sight is very likely to cause pain or disturbance of function somewhere. They claim that this modern ophthalmology is essentially an American development with refinements of diagnosis and treatment that are not practised anywhere else in the world, and they present the history of case after case of all sorts of conditions ranging from simple headache to curvature of the spine which have been relieved or cured by appropriate treatment of the eyes.

The reverse position is taken by many men, including most neurologists and not a few ophthalmologists. They doubt or entirely deny the theory of reflex causation of disease, or at any rate, believe that few serious reflex disturbances originate in the eyes. They rarely find it necessary to use cycloplegics, disbelieve in the necessity of exactness in the correction of refraction and let errors which do not result in actual reduction of vision go uncorrected. The reasonable position to take is somewhere between the two extremes because, while many of the results claimed are possibly due to misconceptions of the condition present, to suggestion, to self-deception, or deliberate deception of others, there is too much clinical evidence accumulating in the records of competent observers to allow the theory to be dismissed without a careful examination.

Definition of Eye-strain.—We say that a patient is suffering from eye-strain when his eyes are compelled to do work which is beyond their physiological capacity. We have no exact standards for measuring the capacity of the normal healthy eye, only a standard of averages. We know that the average patient can read letters of a certain size at a certain distance, but we find many whose acuteness of vision is far beyond the average. In the same way we have an average ability to focus near objects which is greatest in youth and diminishes regularly with age, but this power varies much even in individuals of the same age. We are still worse off when it comes to standards for estimating the important element of endurance. Small wonder, then, that authorities differ widely as to the line which divides the physiological from the pathological. It is perfectly possible to strain even normal healthy eyes by overuse, and this is much more likely to occur under unfavorable conditions and in lowered health, but the chief strain comes from the instinctive effort of the abnormal eye to compensate for some optical deficiency by increased muscular exertion. The hyperopic and the astigmatic can see distant objects clearly only by aid of the ciliary muscles and this effort is vastly increased in continuous close work. Likewise in binocular vision: the eyes when relaxed may be convergent or divergent, but if the extrinsic muscles are powerful enough to rectify the alignment easily, the condition can hardly be called pathological; while if this requires an undue expenditure of energy, eye-strain may be said to be present.

We have to deal in each case, therefore, with an individual muscular problem, and the determination of the exact point where the physiological passes into the pathological depends not only on a proper estimate of optical defects and individual capacity for compensation, but also on a careful consideration of a number of variable factors such as age, health, and the conditions under which the eyes are generally used. Eye-strain is the more easily overlooked because it often accompanies perfect vision and, paradoxical as it may seem, is much more likely to follow small errors than large ones. The patient who has a very large error strains for clear vision, but, after a time, ceases because it is of no avail, and is content with limited vision, while the one with a small error often continues straining because it enables him to see distinctly.

Eyes which are being strained may produce symptoms of several different sorts. First and most common are those which proceed from muscular fatigue. The ciliary muscle, for instance, when tired, ceases to act smoothly and vision is sharp and clear at one instant, and the next is very indistinct. Then come congestion of the ciliary body, with its pains reflected along the nerves of sensation, accounting for many a headache and neuralgia.

Not infrequently, in the effort to supply additional stimulation to the tired eye muscles, adjoining muscles are innervated and we have twitching of the lids or facial muscles. Overstimulation of eye muscles may also deprive other muscles of their normal innervation and the same reasoning applies to secretion as well. In these ways many observers account for the unmistakable stimulation of motor or secretory functions of distant organs which are often seen in eye-strain cases.

Perhaps the condition which is most likely to result in functional nervous disorders is the cerebral fatigue that comes from the constant strain of interpreting retinal images distorted by refractive anomalies. When reading, for instance, we proceed word by word, and not letter by letter; but the astigmatic individual, who easily confuses letters, has to pay much closer attention to his text and is, in effect, reading proof, which is one of the most fatiguing of tasks. To him, all round objects are more or less oval and the square ones oblong, and he is under the necessity of performing a constant series of mental judgments as to the actual form of external objects.

In demonstration of this theory we must not expect the absolute proof that would be required in organic diseases of germ origin. To be sure, we can cause some of the conditions, such as headache, by creating with glasses an artificial eye-strain but we must often fail because of the enormous variations in individual susceptibility to strain and ability to compensate for it. Even the effect of strain in the same individual will vary greatly from time to time, according to this bodily health and the demands on this stock of nerve energy.

Even from the clinical standpoint we fail of perfect demonstration, for the relief of one or two cases is only presumptive evidence. A whole series of similar cases would be far more valuable, while even a single case in which definite symptoms are relieved by eye-glasses and recur when they are left off would be entitled to some attention if we could more definitely exclude the therapeutic influence of suggestion. This element should never be forgotten, particularly in the large class of neurasthenics and hysterics of whom a great authority has said "if they think themselves well they are well." Such patients who have been in a state of depression and despondency, have explained to them a novel theory which not only accounts for their symptoms but offers a definite plan of relief, and, if they have been at the same time subjected to the mental and physical effects of cycloplegia and a routine of impressive and mysterious instruments, a suggestive therapeutics of the most powerful kind is being used. In no other way can we account for the occasional happy effects of glasses which, through some blunder, really increase the strain they were intended to lessen.

I think we are justified in considering it as a perfectly legitimate agent so long as it is not made the excuse for careless or defective work, particularly because suggestion of this sort is renewed every time the patient puts on or takes off his glasses.

Objective Symptoms.—There are a number of rather indeterminate symptoms which frequently indicate eye-strain though some of them may also result from other conditions. In the first place there are certain anatomical conditions of the skull which must necessarily be accompanied by eye-strain, such as inequalities, by which one eye is on a higher plane than its fellow or further from the mid-line, or further from the object of regard; or in which the eyes are noticeably strabismic.

There is another set of symptoms marked by screwing of the lids in myopia and astigmatism, the elevation or depression of an eyebrow, the formation of abnormal wrinkles in the brows and at the angles of the eyes, the constant blinking of the lids and the tilting of the head in unnatural positions in the effort to see distinctly. Many chronic inflammatory conditions of the lids and conjunctiva are also evidences of congestion from straining; but there are many cases in which there are no definite indications to show whether a given set of symptoms proceed from the eye or from some other source and we can only proceed on a plan of excluding one organ after another. It is a rather curious fact that patients who have objective symptoms of one type very often entirely escape those of the other. The patient with a blepharitis often shows none of the muscular twitchings or disturbances of sensation, such as headaches, while the eye-strain neurasthenic often appears, both to himself and to others, to have absolutely no ocular abnormality.

But there are certain conditions which are so often dependent on eye-strain that we are justified in assuming its presence in a large proportion of patients, while in others, in which the connection is only occasional, the assumption should be made much more cautiously.

Headache.—The reflex symptom which is oftenest the demonstrable result of failing ocular compensation is headache. That this is true is proved not only by the readiness with which many persistent headaches yield to proper glasses, but also by the ease with which they can be caused by improper ones. The great majority of our profession have, I think, accepted this view in theory, but in practice I doubt if there is any adequate conception of the enormous proportion which are so caused.

Ocular headaches are of two kinds, accommodative and muscular. The first usually occurs in individuals who are hyperopic or astigmatic but who see perfectly by the aid of a ciliary muscle hypertrophied by use. If the strain is too great one of the first indications of failing compensation is a headache more or less severe that comes on when the eyes are steadily used, and is relieved only by longer and longer periods of rest. Such headaches are usually frontal and vary in character from a dull ache to one so constant and severe as to cause suspicion of some organic disease. The ciliary muscle, like other muscles, after prolonged periods of inaction, loses any previously acquired hypertrophy and its ability to perform work varies with the general bodily health. For instance, a patient whose sight has always been perfect and painless is confined, or has typhoid, or develops some wasting disease. The ciliary muscles fail with the other muscles of the body and headaches begin. Such an ache is, of course, in a sense the result of illness, but it would not occur if the ocular compensation did not fail. It can be relieved through the long period of convalescence by suitable glasses. In the same way the headache in anæmia and disorders of metabolism is very often simply an indication of insufficiency of a badly fed ciliary muscle.

Another type of headache results from imbalance of the extrinsic muscles of the eyes. Our eyes may diverge when relaxed, but with a good, strong pair of interni we manifest no symptoms even when our work calls for continuous convergence. But if the extra stimulation needed is great, or the muscular power is so reduced by ill health that the compensation cannct be maintained, the eyes are exhausted by the continuous effort to avoid diplopia, and a very annoying type of headache ensues. In my experience these pains are more apt to be referred to the occiput and nape of the neck than to the forehead, though accommodative and muscular asthenopia so often go hand in hand that the distinction is not a clear cut one.

As a rule an ocular cause may be suspected in all headaches which occur regularly and get worse in the afternoon, which are increased by close work and relieved by rest and on holidays, or which occur only during certain occupations, like the theatre headache or that which comes from traveling by cars or sightseeing. It would seem that headaches which occur irregularly and at long intervals were probably not due to eye conditions, but there are many exceptions.

Migraine is a term often misapplied to any severe headache, but true migraine is said by neurologists to be a kind of sensory epilepsy characterized by an aura, a headache, and gastric symptoms. The aura is generally a visual one taking the form of amblyopia, or in many cases scintillating scotomata are seen. The pain is almost always a hemicrania and may persist for days, the attack being often complicated with intense nausea and vomiting. It often begins in childhood, is worse during early adult life, and declines both in frequency and severity after middle age. In many cases it can be traced through several generations of the same family.

There are very many atypical and abortive attacks in which one or more of the symptoms are lacking and one should be cautious about making a positive diagnosis, but many temporary amblyopias, hemianopsias and scintillating scotomata, many so called bilious headaches and the like are probably related closely to migraine.

The theory is that a patient inherits or develops a state of unstable nervous equilibrium in which reflex irritation beyond a certain degree excites an explosion. This irritation may come from many sources besides the eyes, but there is a very large mass of testimony now on record as to cases entirely or largely relieved of their symptoms by proper treatment of the eyes. There are, too, many patients whose hereditary instability is so great that an explosion may occur from any one of several exciting causes. Suitable eye treatment might prevent some of these attacks, but not all.

Epilepsy.—In the same way there is a clinical basis for the assumption that eye-strain may be a factor in some cases of epilepsy. Every such patient has, of course, an underlying nervous instability, inherited or acquired, without which no amount of reflex irritation would cause an attack. In the sense of removing the underlying condition one would hardly expect a cure but there are many cases on record in which undoubted epileptic seizures have entirely ceased after suitable eye treatment. The eyes should be examined carefully along with the other organs from which reflex irritation is most likely to occur. The prognosis is, of course, much better in childhood before the attacks have become a habit with the patient.

Chorea is another disease whose dependence on ocular insufficiency has been suspected. But there is a wide diversity of opinion as to just what chorea is. Even the true chorea of Sydenham may not be an etiological unit according to many observers. If one considers the disease an infectious one he would hardly expect to treat it with success through the eyes; on the other hand if one adopts the opinion of other good clinicians that chorea is a functional brain disorder, it is not so difficult to see how it might depend on morbid eyes. Until some means of positive etiological diagnosis is possible the treatment must be more or less an empirical one, and the results various. The course of the disease is also so irregular that rapid improvement might often be in spite of, rather than because of, the treatment whatever its nature. The various habit spasms which have many resemblances to chorea, but whose nature is entirely different, are often amenable to ocular treatment.

Neurasthenia and Psychasthenia are terms generally applied to the symptoms of a class of patients who are nervous, irritable, depressed, easily fatigued, physically or mentally, and complain of various functional disturbances without discoverable organic cause.

These disturbances are often confined to one organ which is considered by patient and physician the seat of the disease and we therefore have cerebral, spinal, cardiac or sexual types. Some individuals inherit a nervous system so irritable that they are from birth unable to cope with the ordinary worries of life, but most neurasthenics date their breakdown from some illness or shock. More often it is the culmination of a long period of overwork or excess. There is no factor that plays a more important part in acquired neurasthenia especially of the cerebral type than the overuse of eyes whose compensation is strained. There is no organ in the body where excess is so common and so surely disastrous.

The benefit which neurasthenics often derive from rest cures, vacations, and the like, is often, in large part, due to the practical relief from all close eye work till compensation is temporarily re-established. This is one reason why neurasthenia is so much more common in early middle life.

This is the period which usually determines success or failure in life, when work and anxiety are carried to the extreme but it is also the time when man's accommodative power has finally reached the point where it is barely sufficient for his daily needs. Presbyopia normally begins between forty and forty-five, but in the hyperopic and especially in the astigmatic it may develop much earlier. After long periods of strain and symptoms attributed to many causes the accommodation at last fails so completely that vision is defective, and the eyes receive proper care. The last half of life often offers the strongest possible contrast in its tranquillity and repose. Neurasthenics notoriously never die, because many of them never had any trouble that proper glasses would not cure.

Diseases of Metabolism.—We have a long list of diseases to-day which are generally, and often correctly, attributed to faulty metabolism. The popular plan is to treat them by careful restriction of diet, entirely losing sight of the fact that uricacidemia, indicanuria and the like are often simply the expression of functional insufficiency of the digestive organs resulting from worry, excesses, or continuous nervous tension. Some of these conditions are certainly due to eye-strain. Such common ills as dizziness, nausea, bilious attacks, are often relieved by glasses, while the eyes should never be forgotten as possible sources of functional digestive diseases.

The Menopause.—When a woman of any age between thirty-five and fifty complains that she has headaches, that things get dark before her eyes, that she is tired and irritable and nervous, it immediately occurs to us that this is the period during which sensations of almost any sort are to be expected and ascribed to the change of life. Curiously enough during this same period presbyopia is imminent with its increasing difficulty in reading and sewing, finally culminating in a frank inability to do longer without glasses. Many of the symptoms which women resignedly bear for years could be relieved by the oculist.

Spinal Curvature of the lateral variety is sometimes dependent on defective eyes in this way: Owing to orbital or muscular abnormalities one eye is on a higher plane than the other and to avoid a vertical diplopia the patient carries his head tilted more or less to one side and a resulting compensatory lateral scoliosis follows. Gould has suggested too, that individuals who have a marked astigmatism with an oblique axis, get the most distinct vision of the important vertical lines in letters by tilting the head till the axis becomes vertical.

Spasmodic Torticollis may follow continuous strained postures of the head, resulting from similar optical errors and sometimes as a direct result of accommodative spasm. The possibility of eye-strain as a factor in conditions of which the etiology is so obscure and the treatment so unsatisfactory should not be forgotten.

Differential Diagnosis.—Since most of the functional difficulties alluded to may result from other sources of irritation beside the eyes, it is often necessary to determine as definitely as possible whether the eyes are or are not important factors. This can ordinarily be done in two ways. If we put the patient under atropine we exclude his accommodation, while if we compel him to wear a pad over one eye we also temporarily obviate any muscular fatigue from the effort to avoid diplopia.

The cessation of symptoms under these conditions would point pretty conclusively to the eyes as the source of the trouble and any effect produced by atropine and the pad ought to be capable of perpetuation by suitable glasses or treatment of the muscular imbalance. The converse is not so true. for many cases in which symptoms persist in spite of atropine or bandage, yield after a time to suitable glasses or an operation.

The Treatment of eye-strain will frequently tax to the utmost the resources of the oculist. but in many individuals Nature herself has compensatory powers, and if we can bring the error within the limits of those powers we shall have given all the relief necessary. This is the reason why inexpert work is so often perfectly satisfactory to patients in ordinary conditions. In migraine and many other nervous conditions, however, it is this very attempt at compensation that causes the trouble, and a much closer correction is called for.

In such cases, therefore, it is generally advisable to examine the eyes under several days cycloplegia with atropine, prescribe the full correction for constant wear and if there is reason to expect difficulty in accepting so strong a glass it is often advisable to keep up the cycloplegia for some time. In this way the eyes not only have a period of absolute rest, but as they come out from the atropine they insensibly become accustomed to their glasses. Nevertheless it must be insisted that patients wear their glasses for a time whether agreeable or not and later on if the symptoms have subsided, it is possible to sharpen up the distant vision by a very slight reduction of the correction.

The results are likely to vary greatly in the hands of different men, first, because many of the cases may turn out not to be eye-strain cases at all, and because oculists possess many different degrees of skill, judgment and ability to handle patients. Finally, good results are to be expected only in patients who are intelligent enough to understand that the best glass is not necessarily the one which gives the sharpest vision.

CHAPTER XVIII.

OCULAR MALINGERING.

THE rapid growth of industrial health and accident insurance has made malingering a subject of increasing importance to the ophthalmologist. There is no industrial injury more disastrous to the individual than even a partial loss of sight, while there is none so easy to simulate, so difficult to detect or making a stronger appeal to commission or jury. Mere detection of fraud is not enough, that often being regarded as mere human frailty and not penalized. The chief purpose of the ocular examination is to establish a demonstrable estimate of the actual organic and functional condition of the eyes. The physician should divest himself of bias and seek simply to record actual conditions, though he feels and reciprocates at once the mental antagonism and suspicion of the malingerer as he hesitates over each new test in the fear of committing himself. As a rule it is a mistake to bully or browbeat. The malingerer will be more easily detected if he thinks you believe his story and are merely making a routine examination for a formal record of the facts.

Detection of malingering does not depend on any one or two classical tests but upon an appreciation of the way an eye should function under varying conditions, and on the ability to put the patient rapidly and naturally into positions he does not understand and for which he is not prepared. The simpler and more perfunctory the tests the better if they throw him off his guard. Above all the beginner should be perfectly familiar with a few tests by trying them on himself, and in the more complicated ones be sure that he does not adjudge a man guilty because he has himself misunderstood or bungled his tests. A detailed record of the examination should be preserved.

Comparatively few malingerers claim total blindness or even partial blindness in both eyes though there will be more when the possibilities of toxic retrobulbar neuritis become better known. The usual claim is an exaggeration of the effect of some accident to one eye or an attempt to include in it some pre-existing defect, which may be congenital or acquired and which may or may not affect the sight. The reduction of vision to be reasonably expected from a low refractive error, a corneal macule, vitreous opacities or retinal defects often requires a very nice discrimination. Refractive defects are by all odds the most common causes of reduced vision and the importance of giving them their just value and no more is obvious. The usual careful objective examination should be made before beginning functional tests.

Inquiry into occupation as showing the visual acuity required in every-day life, while a question as to what the patient thinks is wrong with his eyes will often give valuable psychological information. The malingerer will invariably start a long story. Examination with a pocket flash light will reveal any important external disease, opacities in the cornea, the pupillary reactions, and while the patient is off his guard enable you to determine, as he looks at the light, whether he customarily fixes with one eye or both. Retinoscopy, without any cycloplegic, can be done by having the patient look off into the distance and so relax physiologically. It is of course only approximately correct, but it saves time, gives you an idea what the patient ought to see without glasses and the kind of lens needed to improve sight. Many men can get the same result with the ophthalmoscope, while carefully going over the media and fundi. In testing the vision *it is very important to sit and watch the patient* rather than the test cards as so many men do. If you make him read off briskly, keeping him under your eye while he does it, he cannot slyly close one eye. Try to conduct your tests in a way he has not been accustomed to, with an appearance of carelessness and friendliness. Let him read with both eyes open and make him think you are testing his admittedly good eye when you are really blocking it out by strong glasses.

Most malingerers are perfectly familiar with the test charts but know nothing about the visual angle. Your honest man reads at full speed as far as he can and slows up only when he is not sure. The malingerer labors just as hard over the big letters as the small ones. In doubtful cases make several tests at different distances and see if consistent. One of the best means of deceiving the malingerer is by the use of a mirror in which is reflected a reversed trial card. He is entirely unaware that the mirror has increased the distance and reads accordingly.

The pupillary indications of sight have been considered on page 111, a positive direct reaction to light being very good evidence, though not excluding cortical blindness. Even the Argyl-Robertson may be unilateral. Occasionally a man claims to be totally blind in one eye, even refusing to admit a light which contracts his pupil sharply. Often he will not be able to control the redress movement in the screen test (page 217). Instead of testing him laboriously with candle and prisms for diplopia, it is much easier to have him fix a hand flash light with both eyes open, and then interpose a 5-degree prism before the good eye. If the eye is blind or is not ordinarily used in binocular vision it will move in the same direction that the good one does as the prism is rotated before the eye, while if binocular vision is usual it will not move at all but continue to fix the candle. This same method can be utilized at the 20 foot distance. If a rotary prism be placed before the good eye the distant candle will seem to the patient to move evenly toward the apex of the prism if the other eye is blind, while if it has sight, even if the patient denies diplopia the light will be stationary as long as fusion exists and then seem to jump instead of moving evenly. (Lack of binocular fixation is of course no proof of blindness.)

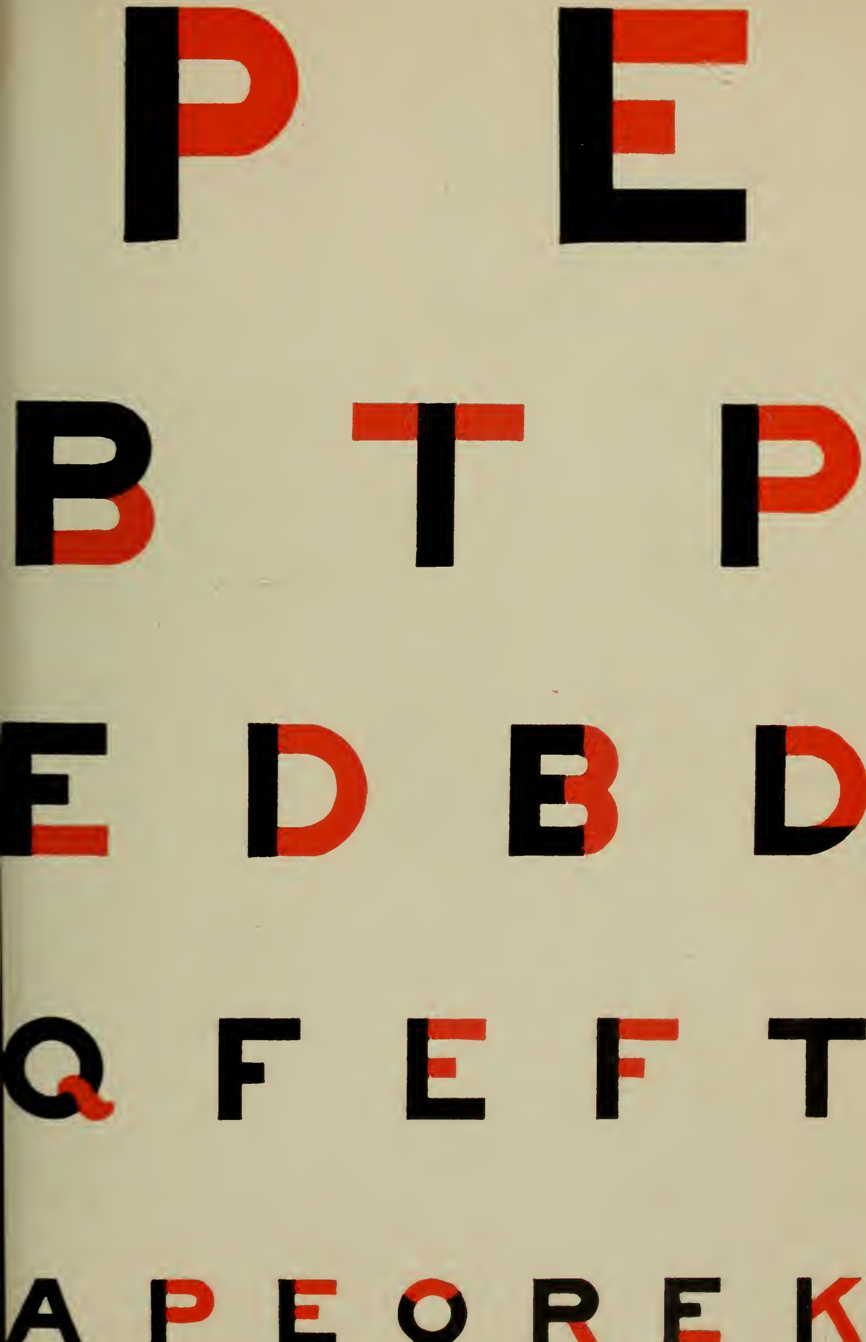
Many methods commonly employed in the testing of binocular vision will suggest themselves as useful in particular cases, as of course diplopia or the slightest evidence of an attempt at fusion will negative a monocular blindness. Most trial cases contain the Maddox double prism. If this is held before the good eye in such a way that the line between the prisms cuts horizontally the centre of the pupil, the patient will have a diplopia without knowing that it is monocular. If he is honest he will admit it at once while if he admits seeing three lights he must be using both eyes. If he admits two lights a card should be carelessly held in such a way as to cover one of the double prisms and if he still sees two lights he must be using both eyes. If he looks at a single line of small type he will see three, the intermediate one belonging to the uncovered eye.

The trouble about these tests is that while they may show fraud and bad faith they give no idea of actual vision present. To meet this need we have a whole series of tests devised to make the patient think he is using his good eye while he is actually using the other. For the successful use of these it is often necessary to put over the poor eye the correction which ought to give it sharp vision while over the good one is placed a glass calculated to make its vision worse than its fellow. Otherwise the patient can tell just which eye he is using by the distinctness with which he sees.

A simple method is to fuss over the bad eye a little and apparently give it up as a bad job, but leaving its approximate correction in place, and then proceed to test the good one with both uncovered. It will very often be possible to gradually block out the good eye with a plus ten glass before the patient realizes that he is reading with his bad eye.

Have the patient read the test chart while looking through the ordinary phorometer. He will see two charts, one up and one down, of which he will claim to see one much more distinctly than the other. If he is asked to read this and then while his attention is distracted the prisms are reversed he will often try and be consistent by claiming to see plainest the same upper or lower card and will read it readily. It is possible to put such lenses in the phorometer cells as to make the vision in the good eye less than the other and make it difficult for him to know which eye he is using if he is prevented from closing one of them.

One of the best known tests is the so-called red and green glass one, in which the patient with a red glass before one eye and a green one before the other looks at a glass chart illuminated from behind with alternate red and green letters etched on it. The red letters are seen through the red glass and the green through the green one. The value of the test is much reduced by the fact that there is only one chart on the market which every malingerer has seen in the optician's window, while the illumination and the colors of the glass must be exactly right. It also fails to give any definite measure of vision. A much simpler test, which would be especially effective on a malingerer who had been coached on the foregoing one, is as follows: If you put a red glass before the good eye and by having the patient look at a red light or a white card establish the psychological impression that he ought to see red with this eye and not with the other, you can then direct his attention to a neighboring card containing alternate red and black letters, and ask him to read rapidly. The red letters on the white ground cannot be seen through the red glass while the black ones are perfectly visible. If he refuses to read any letters he is of course a malingerer, while any red ones seen must be with the alleged bad eye. Another modification of the test consists in placing a green glass over the poor eye and the red one over the good and have him read from the chart without letting him know that there are any colored letters on it. Through the green glass the red and black letters look the same color and the malingerer does not have his suspicions aroused, while the red glass over his good eye prevents his seeing the red letters with it. "Confusion" letters can be constructed, partly black and partly red. Seen through the green glass they appear black, while through the red one the red parts disappear and the letters are entirely different. Red against white is invisible through the red glass, but if the background be black or dark, or even if the red letter be only outlined with a thin black line it becomes visible at once though it appears white instead of red. One can easily construct a card of red letters, which look superficially just alike and yet part of them are absolutely invisible through a red glass while the others appear outline letters in white. These tests can be used for near as well as distant vision, can be



Test Types for Monocular Malingering. To illustrate page 372.
(Place red glass before the good eye.)

8 0

7 5 3 1

2 9 4 6 5

8 3 7 5 6

2 4 6 8 9

0 3 7 0 5

Test Types for Monocular Malingering. To illustrate page 372.
(Place red glass before the good eye.)

combined with the various stereoscopic and fusion tests, while the advertising pages of any modern magazine will supply an infinite variety of letters and labels and pictures printed in red.

The ordinary stereoscope may be most useful, with the charts commonly employed in training the fusion, part of each picture being seen with each eye. For instance, in the chart shown in Fig. 123 the central heavy crosses ap-

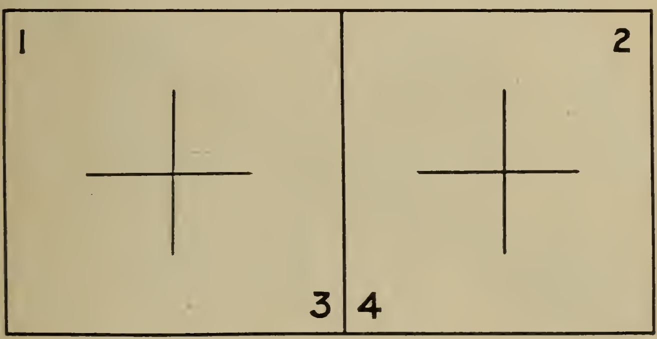


FIG. 123.

pear alike to both eyes and are fused into one. If the patient is using both eyes he sees all four numbers, 2 and 4 being actually seen with the right eye. Through the stereoscope however, 3, which is actually seen by the left eye appears to be almost directly under the 2, and both being on the right of the combined picture seem to be seen with the right eye.

It is easy enough to make up your own cards with print for which the rapid reading requires the use of both eyes, and the reverse cards which can be read easily with either eye alone but not with both together. In using a stereoscope great care must be taken that the patient does not close his pretended bad eye and so deceive you. It is better to cut away most of the hood of the instrument.

The person who claims poor vision in one eye will generally admit very good in the other. For this type the bar reading test is a good one, having him read fine type with both eyes open while you hold a pencil or fountain pen vertically four or five inches in front of him. If he reads

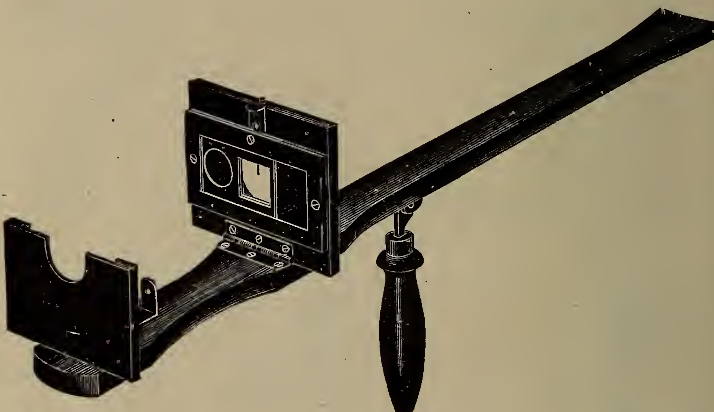


FIG. 124.

without hesitation or twisting of his head he must be using both eyes.

One of the simplest and best means of detecting the malingerer is the diploscope. (Fig. 124.) It consists essentially of a diaphragm with a central opening through which a row of letters is seen with both eyes open. The impression is that the letters are all seen with both eyes while as a matter of fact those on the left are seen with the right eye and *vice versâ*. The fakir who does not understand the principle involved is very apt to insist that he is seeing the right letters with the right eye, which is impossible. Unfortunately the device is not practicable for distant vision.

The amblyoscope (Fig. 100) can also be made very useful. In all possible positions of the tubes the card in the right tube can only be seen with the right eye and *vice*

FIG. 125.

versâ but when the tubes are approximated the right card as reflected in the mirror appears to be on the left of the other and therefore to be seen with the left eye. When the tubes are widely separated the cards are seen homonymously while in the intermediate position they may be fused. In this last position cards can be used with alternate lines or figures on each so that smooth reading or accurate description implies the use of both eyes, while a further source of confusion can be introduced by having the stronger illumination in front of the poorer eye.

My own "malingeroscope" (Fig. 125) consists of two short parallel open tubes the distal ends of which are covered by loose caps which can be rotated and which contain a small eccentrically placed aperture. By rotating the caps the distance between the apertures can be made greater or less than the interpupillary distance while being kept in the same plane. In the last position for instance, if the patient looks at a distant chart with both eyes open he is conscious of two holes, the one actually before the right eye appearing to the left of the other. If you tell him you will cover his alleged bad left eye and slip a card over what appears to him as the left hole you are actually covering his good right eye and *vice versâ*. If he looks at two wall charts 20 feet away and 18 inches apart he can see both, the left being seen with the right eye but apparently with the left eye through the left hand hole, and *vice versâ*. If two exactly similar charts are used many patients will fuse them, seeing one hole and one card, and if extra letters are interpolated at different places on each card will read them all as though they were on one. A still further source of confusion can be introduced by unobtrusively holding a suitable lens over the aperture corresponding to the good eye and making its image less distinct than its fellow.

Another series of tests is based on an attempt to make an alleged defective eye interfere with the vision in the good one. For instance, as the patient reads the wall chart with both eyes open, a five degree prism base up is moved back and forth before his poor eye. If it is really blind it will cause him no inconvenience, while if it has any function at all the constant doubling of the test will perceptibly interfere with the smoothness of his reading. The same idea can be used in near vision to even better advantage, and is even more effective if applied to various projection and orientation tests. For instance if you hold up a finger ring and ask him to pass a pencil through it or to thread a large needle or to catch a ball, the denied diplopia will often be very apparent.

There are cases in which the field of vision is important. For instance policemen, seeking premature retirement on pension often present all the symptoms of chronic retrobulbar neuritis in which there are no very definite objective symptoms but a considerable bilateral failure of central vision. They are very apt to be unaware that they should have a central or paracentral scotoma for red and green, with an enlarged blind spot, and generally give a field of the hysterical type, extremely contracted, with the white and color fields nearly equal or even inverted, and when tested at different times and distances yielding very inconsistent results. They are also very susceptible to suggestion by the examiner if it is artfully done. In these cases too the scotomata should be generally relative and the vision ought to vary widely with the brightness of the illumination and with the color of the letters used in testing the central vision.

Hemiopia seldom suggests itself to the malingerer unless he has been previously coached or known some one with this defect. Its probability would be enhanced by the hemiopic pupillary reaction or some of the other lesions like hemiplegia which so often are associated with it. In mapping its fields the honest patient will usually show a vertical line passing almost through the fixation point, as the boundary between the blind and seeing halves of each retina, and this does not change. In testing the malingerer it is advisable to map out the field on the blackboard or curtain, marking plainly its limits, and then after an interval go over the same ground a second time with the point of fixation shifted a few degrees. He is very apt to stick to the original limits. The stereoscopic chart shown in Fig. 123 is also very useful. In a right hemianopsia, if enough central vision remained as is usual the central crosses should be fused and seen as one. In actual right hemianopsia the figures 2 and 3 could not be seen. The malingerer who saw all four would be very apt to assume that 2 and 4 were the ones to be denied, if he had carelessly been allowed a good look at the card before it was put into the stereoscope. In right hemianopsia the honest man reads from left to right very badly for he is reading into the blind area while he would read letters much faster in the other direction. The left hemianope has his difficulty in finding the beginning of the next line.

If the patient has good central vision in both eyes advantage can be taken of the fact that in the diplopia tests, either far or near, the sudden interposition of a weak prism that throws one image on a really blind half of the retina would not cause any diplopia or fixation movement in fusion while in the reverse direction it would.

INDEX.