OPTOMETRIST'S MANUAL

A Treatise on the Science and Practice of Optometry

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VOLUME I

Anatomy and Physiology of the Eye, Principles of Refraction, Light and Lenses, Eye Examination, Sight-testing Equipment, Presbyobia

WITH ILLUSTRATIONS

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OPTOMETRIST'S MANUAL

VOL. I

PREFACE TO VOL. I.

THE original treatise, which this volume succeeds, was first published in 1897 under the title "The Optician's Manual." It had the distinction of being the first authoritative work published in the United States devoted solely to the science of eye-refraction and the art of sight-testing and spectacle fitting.

The practical value of the work has been well attested by the enormous demand for it, requiring new editions in rapid succession.

In the present edition the title has been changed to "Optometrist's Manual" as better expressing the character and scope of the subject matter of the work, a change, by the way, which should have been made long ago, for the practitioners of drugless eye-testing and eye-glass fitting have for some years been known as optometrists.

But tradition and sentiment bind one to a book title as they do to a name. Both author and publisher have therefore, been loath to change a title that has meant so much to a large majority of those who practice optometry and who obtained the groundwork of their optical and ocular knowledge from this and its companion, Volume II.

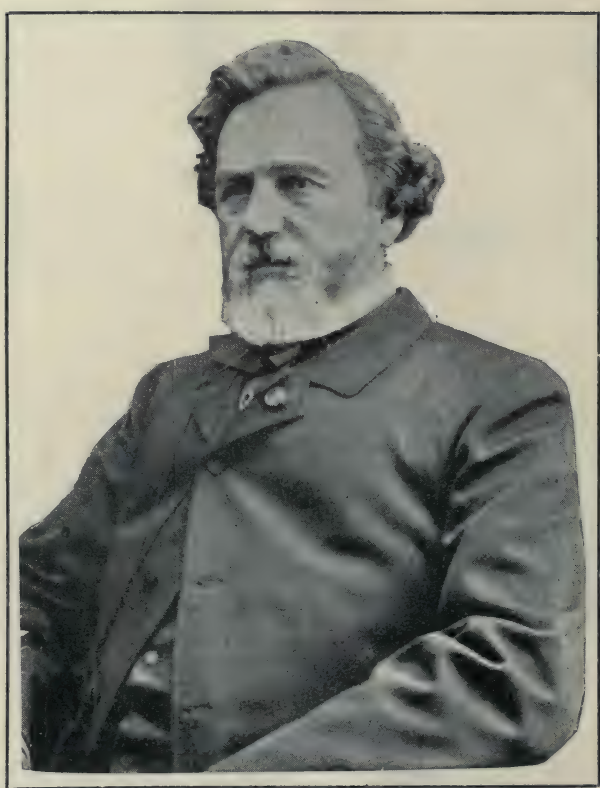
A concurrent edition of the second volume has been printed under the new title, both being revised before reprinting.

"Optometrist's Guide," Volume I and II form the most comprehensive single treatise on the essentials of optometric science and practice available to student and practitioner.

Under its new title this work, we hope, will continue to find an ever-widening circle of students and friends as has its predecessor under the original name.

THE PUBLISHERS

CONTENTS



Prof. Donders

Prof. F. C. Donders

To whom the optical world concedes the distinction of being the father of practical ophthalmology, was born on May 27, 1818, in Tilbury, Holland. He was the ninth child and first son of poor parents, and while yet in his infancy lost his father. His solicitous mother, however, contrived to procure for him facilities for education, and such was the precocity of this remarkable boy that ere he reached his teens he had so mastered the Latin language that he was earning his living as a sub-teacher in a classical school. He continued his studies of Latin until his seventeenth year, and his mastery of this useful language served him well in his subsequent professional career. He began his medical studies in the military school of Utrecht, and from the first day of his student-career he manifested that industry and aptitude in scientific research which were destined to make his name immortal. When twenty-two years old he occupied the chair of military surgery at La Haye, and two years later he was professor of anatomy and physiology at the same medical school in Utrecht at which he began his medical studies. In 1889 he died in this same city of Utrecht, after a career of successful research that entitles him to the lasting gratitude of humanity and to a niche in the temple of fame, side by side with the greatest luminaries of this great century.

While Donders did not limit his wonderful intellect and tireless industry to any single subject or science, the optical world is particularly indebted to him for his achievements in ophthalmology. His researches in hypermetropia and astigmatism gave to ophthalmology a new and wider meaning, practically developing it from an experimental into an exact science. His principal optical works are "Study of the Movements of the Eye," "Astigmatism," "Anomalies of Accommodation and Refraction of the Eye." There are other and great men who owe immortality to their valuable researches in ophthalmology, but none who more deserves the gratitude of humanity than Professor F. C. Donders.

CHAPTER I.

INTRODUCTORY.

The first use of spectacles was, probably, for the correction of presbyopia, or old sight, about six hundred years ago; and to Roger Bacon is generally given the credit of the first knowledge of their use.

For many years after the discovery of spectacles their use was confined to supplying the deficiencies of the eye consequent on age, and no special advancement in their use was made. During the past half century, however, the subject has been carefully studied by eminent specialists, and the greatest advances have been made in the treatment of the eye and its diseases, and the correction of the various optical defects by properly adjusted glasses.

Any one who reads the history of ophthalmology and compares the past with the present is forced to the conclusion that the advancements that have been made are little short of marvelous. Fifty years ago the whole subject was shrouded in mystery and uncertainty. Hypermetropia was not known as the factor in the causation of so much headache, eye-ache and neuralgia, and of so many cases of blurred sight and irritable eyes; these cases were not understood, and hence were looked on as incurable, or classed under the general head of amblyopia. Myopia was recognized by its subjective symptoms, but was not known to depend on a lengthened eyeball caused by a diseased condition of the fundus of the ball. Astigmatism had been heard of, but its true significance was far from being understood. Strabismus and diplopia, in all their varieties, were recognized by their objective and subjective symptoms, but the theory of binocular vision, the action of the ocular muscles, and the possibilities of the benefit to be derived from prisms, were as yet undiscovered truths.

Perhaps in no other branch of science has such progress been made, so much valuable relief to suffering humanity been furnished as in this science of ophthalmology; and the advancements made have all been in the direction of simplicity as explained by the well-understood physical laws of optics, which account for so much that was formerly obscure and unintelligible. To the beginner the study of optics seems to present many difficulties and to be surrounded with almost unsurmountable obstacles. But these difficulties and obstacles are more imaginary than real, and as rapidly disappear before a zealous student's application as the morning dew before the sun.

The subject may, for simplicity's sake, be said to be comprehended under three heads:

FIRST: A knowledge of the eye anatomically and optically considered, which includes the normal and the ametropic eye, the various defects to which it is liable, and the proper adjustment of glasses for their correction and relief.

SECOND: A knowledge of some of the simpler laws of optics.

THIRD: A practical knowledge of lenses (simple and compound), their action on rays of light, and the laws that govern their adjustment.

The reader will see from this that a little time well applied in study and thought will open up to him a large, fruitful and well-cultivated field, covered with much fruit of scientific and practical knowledge, which he can have for the picking; and hence all are urged to commence the study of the subject with confidence in their ability to thoroughly master it and to make practical use of it in their everyday business life.

No age is now exempt from the use of glasses. They are placed on a child that is little more than able to talk, as well as on the aged patriarch who finds them indispensable to his happiness and comfort. Indeed, it is an indisputable fact that every person who lives to reach the age of fifty or more requires glasses at some period of his life, either for reading or distance. To many persons they are an absolute necessity at all ages, while those persons whose eyes are perfectly emmetropic require them for reading in middle life, on account of the changes wrought in their eyes by age.

Those rare cases we sometimes see or read of, where persons have never worn glasses and are able to read all their life without them, are but the exceptions that prove the rule; they are almost invariably myopic, but are not conscious of it; or, if they are, they refuse from mistaken notions to wear glasses, preferring to sacrifice their distant vision. It is the myopic condition of the eyes that enables them to read without glasses; but the fact remains that they require glasses to make their sight perfect for distance.

The affections of refraction and accommodation of the eye are constantly assuming more and more importance, and are engaging more and more the best thought of the most skilful ophthalmologists. For it is now known—indeed, the extensive use of glasses has proven—that a large and ever-increasing class of eye troubles (as, for instance, some forms of asthenopia and amblyopia), which were formerly considered incurable by any remedial measures, are not due, as was supposed, to organic change and disease of the structures of the eyeball, but are, in reality, dependent upon some anomaly of the refraction or accommodation, and hence are now found to be readily amenable to glasses; and diseases that heretofore could not be checked by any of the means known to the physician are now promptly arrested in their progress and cured by the adjustment of the proper lenses.

Although the use of glasses was at first due to an accidental discovery, their adjustment is now placed on a higher plane, which is controlled by the unvarying laws of mathematics.

Persons with weak eyes, and some who were never conscious of any defect in their sight, are enabled by a careful adjustment of glasses to see in a manner they never before thought possible. Others, who were compelled to abandon their chosen callings on account of failing sight, are sent by the oculist or optometrist back to work with eyes practically as good, and in some cases better, than ever. Even cross-eyes, sore eyes, and some affections of the lids can be cured by the proper adaptation of glasses.

In view, then, of the great value of glasses to every individual at some period of his life, and of their absolute necessity to many others at all ages, it is high time that all prejudice against their use should be done away.

The greater the advances that have been made in the investigation of the affections of refraction and accommodation, the more evident it has become how very necessary it is that they should be thoroughly and carefully studied and scientifically treated. Optometrists will, therefore, realize the necessity of making themselvesperfectly familiar with just such knowledge as is presented in this volume, always keeping in mind the fact that it is only by applying the knowledge so gained to the practical examination of a large number of cases that he can expect to acquire the requisite facility and experience necessary to satisfactorily and accurately adjust glasses for the correction of the various disorders of refraction and accommodation as met with in daily practice.

CHAPTER II.

THE EYE ANATOMICALLY.

Every one must admit that an organ which is so necessary to our usefulness and happiness as the eye cannot be unworthy of our serious attention; indeed, the intelligent care which should be given to such an important member of the body requires some knowledge of its structure and function. Even apart from this, it would be natural to suppose that a subject so interesting and important would surely attract the attention of every educated mind; but, alas, the universal testimony of all those observers who have the best opportunities for ascertaining the true facts is that such is not the case, but that the people generally know almost nothing about the structure of the eye or the care of the sight.

In these days the intelligent optometrist is expected to know pretty nearly everything about the eye, and on account of the prevailing popular ignorance on the subject, he will be asked all sorts of questions about it, and he will be constantly looked to for advice when the eye or sight becomes affected in any way. If the optometrist is able to meet any reasonable requirement in this direction, he will inspire his patrons with confidence in his ability to successfully fit them with glasses, and thus add much to his reputation as a skilful optometrist.

The limits of this work, however, permit but scarcely more than a brief outline of this branch of the subject—just sufficient to afford an intelligent idea of the anatomy and physiology of this wonderful organ—and to lay a sufficient foundation upon which the more practical branches, which are to follow, can be securely rested.

THE EYEBALL.

The eyeball is nearly spherical in shape and measures about an inch in diameter. A glance at the diagram will show that there is a segment of a smaller sphere engrafted upon the anterior portion of the larger sphere, and, consequently, if the antero-posterior diameter (that is, from before backward) is

24.5 mm., the transverse diameter would be about one millimeter less. The diagram also shows that the larger sphere forms about five-sixths of the globe, and the remaining sixth is made up by the segment of the smaller sphere.

For convenience of description, the eye is regarded as consisting of three *humors* contained within three *membranes.*

The humors, counting from before backward, are:

1. The Aqueous Humor.
2. The Crystalline Lens.
3. The Vitreous Humor.

The membranes, counting from without inward, are:

1. Sclerotic and Cornea.
2. Choroid, Iris and Ciliary Body.
3. Retina.

THE SCLEROTIC.

The sclerotic is the external coat; it is a tough, fibrous membrane, having almost the resistance of leather, and is about one-twenty-fourth of an inch thick. It is the skeleton or framework of the eye, without which its shape could not be maintained, although it would allow the eye to partly collapse if the contents of the ball are evacuated.

The sclerotic is white and glistening in appearance, and is popularly known as "the white of the eye." It furnishes attachments for the external muscles that move the eyeball, and indeed all the tissues, membranes, muscles, etc., are attached to it, either directly or indirectly dependent upon it for support. It practically surrounds the eyeball, covering the larger sphere, or the posterior five-sixths of the globe of the eye.

The sclerotic is pierced behind by the optic nerve, a little to its inner or nasal side. The nerve does not enter as one large bundle, but divides and passes through numerous openings in the sclerotic, which are called the *lamina cribrosa.* The sclerotic is much thicker behind than in front, where, as it thins out, it passes (with some changes in its structure) into the cornea, so that the entire external membrane of the eye is continuous as a single membrane. The sclerotic is an opaque membrane, but as it passes into the cornea it loses these elements, which render it opaque, and becomes colorless and transparent. The sclerotic is but poorly supplied with blood, as shown by its glistening white appearance.

Anteriorly near the junction of the cornea and sclerotic, completely encircling the cornea, but situated in the tissues of the sclerotic, lies a circular sinus, called the *Canal of Schlemm*. There has always been some question as to its exact function; but it is now generally regarded as a venous channel, the purpose of which is to drain the aqueous humor of the anterior chamber.

The anterior portion of the sclerotic is covered by conjunctiva which is reflected from the upper and lower lids; the posterior portion is embedded in the capsule of Tenon, from which it is separated by a lymph space, thus allowing free movements of the eye.

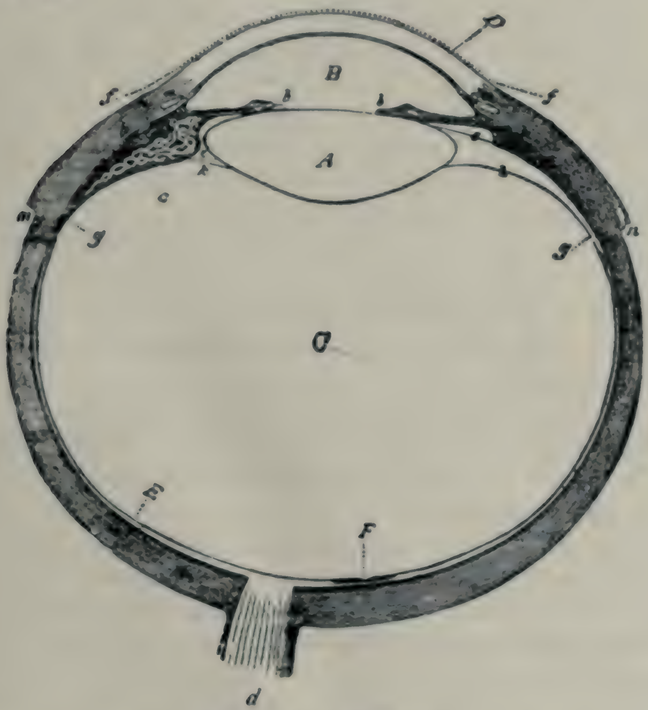


FIGURE OF THE EYE.

A The Crystalline Lens.
B The Aqueous Humor.
C The Vitreous Humor.
a a The Canal of Schlemm.
b b The Iris, the opening between being the Pupil.
k The Capsule of the Lens.
f f The Epithelial Covering of Cornea.
m n The insertion of the Muscles in the Sclerotic.
D The Cornea.
E The Retina.
F The Yellow Spot.
d The Optic Nerve.
h h The Ciliary Body.
g g The Choroid Coat.
e The Zone of Zinn.

THE CORNEA.

The cornea is the projecting transparent portion of the external coat. It is joined to the sclerotic very much like a watch crystal is set in its case. Its degree of curvature varies in different individuals, and in the same individual at different periods of life, it being more prominent in youth than later in life, when it gradually flattens.

On account of its transparency, we look directly through it and see only the colored iris and black pupil behind it, and hence it is best seen by looking at it from the side or by reflected light. Although colorless and transparent, the cornea is tough and unyielding, and thus supplements the sclerotic membrane in the protection of the contents of the eyeball.

The cornea is the window of the eye, "through which the individual looks out into the world"; and as the window-pane should be of good quality and cleaned from dirt in order to afford a distinct view of objects, so care must be taken to preserve the brilliancy and transparency of the cornea. If the relative position of the cells composing the cornea be altered by pressure from within or without, it becomes steamed and cloudy, as also happens in injury or inflammation of this structure, when its usefulness is correspondingly diminished. No matter if every other part of the eye be normal, with an impaired cornea perfect vision is impossible.

One peculiarity of the cornea is that it contains no blood-vessels, all of them terminating in loops at its circumference.

The cornea is composed of five layers, as follows:

1. Epithelium.

2. Anterior limiting layer, or *Membrane of Bowman,* a dense membrane, which maintains the shape of the cornea.

3. The proper substance of the cornea, not as dense as the preceding, but forming the greater part of thickness of the cornea.

4. Posterior limiting layer, or *Membrane of Descemet.*

5. Endothelium.

The cornea is freely supplied with nerves.

The average radius of curvature of the anterior surface of the cornea is 7.8 millimeters; of the posterior surface, 6 millimeters.

The thickness of the cornea is the same as the sclerotic, about one millimeter.

CHOROID.

The next, or middle coat, is the choroid, which invests the posterior five-sixths of the globe of the eye and forms a lining for the inner surface of the sclerotic.

This is the vascular and pigmentary coat of the eyeball; that is, it contains most of the blood-vessels of the eye; in fact, it seems to consist principally of a network of blood-vessels, lined with a layer of flat, dark brown or black pigment cells. The blood-vessels supply nutriment to the various parts of the eye, while the use of the dark surface is to absorb the excess of light, which would otherwise dazzle and prevent accurate vision.

The choroid, like the sclerotic, is pierced behind by the optic nerve. As it approaches the front part of the eye, it folds upon itself and forms a series of folds or plaitings, which are known as the ciliary processes, which are arranged in a circle behind the iris and around the margin of the crystalline lens, and they gradually merge into what is known as the ciliary muscle, or the muscle of accommodation.

THE CILIARY BODY.

The ciliary body is composed of two parts:

1. The *vascular part*, supplying nourishment to the vitreous and crystalline, and for the secretion of the aqueous humor. The projecting tips from its anterior portion, seventy or eighty in number, are known as the *ciliary processes*.

2. The *muscular part*, known as *the ciliary muscle*, which consists of involuntary fibres, and consequently is not under the control of the will; it acts automatically on the approach of objects to and their recession from the eye, just as the muscular fibres of the iris when exposed to light or when shaded from it, and hence the ciliary muscle plays an important part in the accommodation of the eye. It is a grayish circular band, about an eighth of an inch broad, on the outer surface of the fore part of the choroid.

The fibres of the ciliary muscles are arranged in two sets: the meridional and the circular. The latter is large and well developed in hypermetropia, where the accommodation is constantly taxed, while it is small in myopia, where there is but little need for the accommodation.

THE IRIS.

The word iris means a rainbow, and it receives this name from its various colors in different individuals. It is this structure which gives to the eye its special color and upon which a large part of its beauty depends. When we speak of a blue, black or brown eye, we mean the color of the iris of that particular eye, and it is usually in accord with the general coloring of the individual, blondes generally having blue and gray eyes, and brunettes brown or black eyes.

It is an interesting fact that the eyes of new-born babes are always blue, and they do not begin to assume their permanent color until the sixth or eighth week of life, being then formed by the addition of a greater or less amount of dark pigment.

The eyes of albinos are pink, not from this color of the iris, but from the reflection seen through it of the red blood in the vessels of the choroid, in which membrane there is also a lack of pigment. The sight of such an eye is always deficient, and they are painfully sensitive to light, against an excess of which they have not the natural protection of a darkly pigmented choroid.

The iris is a thin, circular-shaped, contractible membrane, suspended in the aqueous humor behind the cornea and in front of the lens. It is perforated slightly to the nasal side of its center by a circular aperture, *the pupil,* for the transmission of light, thus forming a curtain stretched across the interior of the eye. There is a popular notion that dark eyes are stronger than light ones; the only foundation for this idea is the fact that they are better protected against excessive light. Hence light eyes prevail among northern nations, and dark eyes among the races who live in the glare of a tropical sun.

The muscular system of the iris is involuntary; that is, it is not under the control of the will, and hence we are not able to change the size of the pupil by the strongest effort of our volition.

The muscles of the iris consist of circular and radiating fibres, known as the *sphincter* and *dilator.* The former surround the margin of the pupil on the posterior surface, forming a narrow band about the thirtieth of an inch in width; these are the fibres that contract the pupil. The radiating fibres converge from the circumference toward the center, where they blend with the circular fibres, and by their action enlarge or dilate the pupil.

Through the action of these two sets of muscles the pupil has the property of changing its size, thus regulating the amount of light admitted to the retina. When we pass out into the bright sunshine of mid-day the pupil immediately and instinctively contracts, to protect the eye from the irritating glare of a flood of light; and when we return to a darkened room it dilates, to admit as much as possible of the insufficient light.

The contraction of the pupil through the sphincter muscle is controlled by the *third cranial nerve;* the dilation through the radiating fibres by the *sympathetic nerve.*

Belladonna, or its active principle, atropia, if applied to the eye or taken to excess internally, dilates the pupil widely; while eserine and pilocarpine contract it. Opium also has the effect of contracting the pupil, and this is one of the first symptoms looked for when opium poisoning is suspected. When we are not looking at anything closely, or when we look at a distance, the pupils dilate, as is also the case in meditation. The pupil grows smaller with the advance of years, and by shutting out diffusion circles partially compensates for the impaired vision of old age.

The pupil appears black because of the lack of intraocular illumination for the same reason that a small opening into a dark closet is black. The pupil can be illuminated and made to appear of a bright red color by the reflected light from the mirror of an ophthalmoscope, just as the closet can be lighted by a candle held near its door.

THE RETINA.

The internal or nervous coat of the eyeball is called the retina, and it is the most important membrane of all; indeed, all the other structures of the eye may be considered subservient to this one, as on it are formed the images of external objects by means of which we are said to see them. It is a delicate nervous membrane, upon the surface of which the images of external objects are received.

The retina is continuous with the optic nerve; in fact, it seems to be the spreading out of the nerve, which pierces the sclerotic and choroid to form this membrane, and by means of which the impression is carried to the brain, and hence the eye and the brain are in the most direct and constant communication.

In order that the retina may properly perform its function it is necessary that it should be in a healthy condition, and if not the sight is correspondingly impaired. The retina may be compared to the paper on the walls of a room, and, like wall-paper, it sometime becomes loosened, as in "detachment of the retina," which is apt to occur in cases of extreme myopia, and results in serious impairment of vision, and even total loss of sight.

The retina corresponds to the delicate film of the photographer's camera, which receives the image of an object and allows it to be stamped upon its surface. There is one great point of difference, however: while the film of the camera is confined to one impression, the capacity of the retina is unlimited. The image of one object after another is formed on the retina as quickly as the eye can move and change its point of sight.

In the center of the posterior part of the retina, at a point corresponding to the axis of the eye in which the sense of vision is most perfect, is a round, elevated, yellowish spot, having a central depression at its summit, called the *fovea centralis,* which is the center of direct vision and the most sensitive part of the retina. The retina in the vicinity of this *yellow spot* is exceedingly thin, so much so that the dark color of the choroid can be distinctly seen through it, and makes it present almost the appearance of an opening.

In the region of the macula lutea (which is the Latin term for yellow spot) the rods begin to be replaced by cones, so that at the macula there are no rods at all, while the number of cones is great, which, therefore, makes the latter the most prominent feature of the fovea.

About one-tenth of an inch to the inner side of the yellow spot is the point of entrance of the optic nerve, which is the only portion of the surface of the retina from which the power of vision is absent. It is important for the optometrist that he possess a clear idea of the relative positions of the yellow or sensitive spot and the optic nerve entrance, or blind spot. Some persons think that the latter is directly in the center of the posterior part of the eye, but the fact is, this point is occupied by the former (yellow) spot. These facts can perhaps be better impressed on the mind by the illustrations.

The retina is a very delicate and extremely complicated structure. Though its greatest thickness does not exceed one-one-hundred-and-twentieth of an inch, yet microscopists have described some eight or ten different layers. It will be sufficient for our purpose, however, to consider it as composed of three layers:

External, or Columnar Layer.
Middle, or Granular Layer.
Internal, or Nervous Layer.

The central artery of the retina, with its accompanying vein, pierces the optic nerve and thus enters the cavity of the eyeball. It immediately divides into four or five branches, and later forms a fine capillary network of blood-vessels.

THE OPTIC NERVE.

The optic nerves (the second pair of cranial nerves), after leaving the eyeballs, run obliquely backward and inward through the orbit to the optic foramen, through which they pass into the cranial cavity, where they join together to form the optic commissure, in which there is a decussation of the nerve fibres, and then pass on backwards to form the optic tracts. These tracts extend from the commissure to the base of the brain, finally entering the geniculate bodies, the optic thalmai and the corpora quadrigemina.

The optic nerve, then, is naturally divided into three parts:

1. *Intraocular.* The nerve fibres passing through the lamina cribrosa and spreading out to form the retina. The head of the nerve or *optic disk* is the most prominent object in the ophthalmoscopic picture, where it appears as a circular white spot.

2. *Orbital.* This portion of the nerve extends from the sclera to the optic foramen. On account of the curve in its shape, the eye is allowed to move freely in all directions without subjecting the nerve to tension.

3. *Intra-cranial.* This part of the nerve extends from the

optic foramen to the chiasm, being one centimeter long, and where the optic nerve proper ends and where the optic tracts begin.

A glance at the diagram shows that it is the fibres from the nasal side of each retina that cross to the optic tract of the opposite side, while the fibres from the temporal side of each

Left Tract Right Tract

Diagram showing decussation of optic nerve fibres.

retina pass back to the brain without decussation. In other words, the right optic tract is made up of the fibres which supply the right side of each retina and the left optic tract the fibres of the left side of each retina.

THE AQUEOUS HUMOR.

The aqueous humor completely fills the anterior portion of the eyeball; that is, the space included between the cornea in front and the crystalline lens and ciliary processes behind. It is small in quantity, and its composition is little more than water with a small quantity of chloride of sodium in solution. The iris floats in the aqueous humor; that is, the humor is on all sides of it.

If this fluid is evacuated by injury or operation, there is a fortunate provision by nature that it is reproduced very quickly, as otherwise the usefulness of the eye would be impaired by the loss of convexity of the anterior portion of the eye and by an adhesion of the iris to the cornea and lens.

THE VITREOUS HUMOR.

The vitreous humor occupies four-fifths of the interior of the eyeball. It fills the concavity of the retina and is hollowed in front for the reception of the crystalline lens. It is perfectly transparent and colorless, of about the degree of density of thin jelly, and consists of an albuminous fluid inclosed in a delicate transparent membrane, called the *hyaline membrane*.

In health there are no blood-vessels in the substance of the vitreous body. On account of its consistency it is admirably adapted to maintain the form of the eyeball and give to the retina, which is spread upon its outer surface, the necessary support, while at the same time it yields sufficiently to protect this delicate structure from injury by jarring or external pressure. If "the eye runs out"—that is, if there is an escape of the vitreous fluid from rupture of the coat of the eye—it is not again re-formed(as is the aqueous humor).

The maintenance of the proper form and distension of the globe of the eye depends largely upon the vitreous humor, without which the ball would collapse into a shapeless mass. It also keeps the choroid and retina in position, so that the latter shall be at the proper location to receive the images formed by the refracting media.

The eye is a wonderful illustration of skilful packing, combining firmness, elasticity, compactness, mobility and safety, in a degree of perfection that can never be approached by art, and is, perhaps, scarcely equaled elsewhere in nature.

THE CRYSTALLINE LENS.

The crystalline lens, enclosed in its transparent and elastic capsule, is situated immediately behind the pupil, and in a depression in the front part of the vitreous humor, and is surrounded by the ciliary processes, which slightly overlap its margin. The lens in its capsule (hyaloid membrane) is suspended at all portions of its circumference, and is retained in its position chiefly by what is termed the suspensory ligament of the lens, which originates in the meshes of the ciliary body, and is firmly inserted at the edge of the capsule.

The crystalline lens is a transparent, double convex lens, the convexity being greater on its posterior than upon its anterior surface. It measures about a third of an inch transversely and about one-seventh of an inch antero-posteriorly. It is firmer than the vitreous, but is not solid, the outer portion being softer, while that beneath is firmer, and the central portion forms a hardened nucleus.

In young persons the consistency of the lens is such as to allow its shape or convexity to be readily altered, this contraction and expansion being accomplished by means of the ciliary muscle. It grows denser with age, and hence is less susceptible to the action of this muscle; it also becomes flattened on its surfaces, slightly opaque and of an amber tint. These changes bring on the condition of presbyopia, as will be fully explained in Chapter X.

The eyeball is imbedded in a soft cushion of oily fat, which supports and protects it and at the same time allows it to move in all directions as freely as if it floated in water.

THE ORBIT.

The *orbit* in which the eyeball is lodged is a hollow cone of bone with its base directed forward and outward. The external edge of the orbit extends much less forward than the internal, and the axes of the two orbits, if followed back, would meet at an angle of 45°; this arrangement permits the widest lateral range of vision consistent with the power of directing both eyes at the same time to a near object; that is, the faculty of binocular vision. The position of the orbit varies in different animals, and in some the eyes are placed so entirely at the side of the head that they can see almost as well behind them as in front. They enjoy a wide range of sight, but do not possess the gift of binocular vision.

The orbits are four-sided, and are formed by seven bones: frontal, sphenoid, ethmoid, superior maxillary, palate, malar, and lachrymal. The opening of the orbit is about 1½ inches high and 1¼ inches wide; its depth is about 1¾ inches. At the apex of the orbit is the *optic foramen,* which transmits the optic nerve and ophthalmic artery. Near this foramen is the *sphenoidal fissure,* which transmits the third, fourth, sixth nerves and ophthalmic division of the fifth nerve, and the ophthalmic vein.

The space in the orbit not occupied by the eyeball, muscles, nerves and blood-vessels is filled in with fat and connective tissue. This tissue forms sheaths for the muscles and optic nerve, and develops a membrane which spreads over the eyeball and is known as the *capsule of Tenon.*

The edges of the orbit are dense and strong, particularly the upper one, which overhangs the eye and is capable of shielding it from a powerful blow, as is illustrated in the case of a "black eye," when the surrounding soft tissues are swollen and inflamed and filled with blood, while the eye peeps through them quite unharmed. When the eyeball itself is injured by the fist, it is always by a blow aimed from beneath.

The *appendages* of the eye include the eyebrows, the eyelids, the conjunctiva and the lachrymal apparatus, consisting of the lachrymal gland, the lachrymal sac and the nasal duct.

THE EYEBROWS.

The eyebrows are formed of muscle and thick skin, covered with coarse short hairs, and rest upon a bony ridge above the edge of the orbit. The hairs are arranged somewhat like the straw on a thatched roof, and serve to protect the eye from the perspiration that trickles down the forehead. The muscles of the eyebrows serve, to some extent, to control the amount of light admitted into the eye, as is evidenced by the way in which they are instantly drawn down when suddenly exposed to a dazzling light.

They have æsthetic functions, too, as powerful organs of expression. A frown is produced by wrinkling and depressing the brows, while by elevating them, incredulity, surprise or contempt can be expressed almost as plainly as by words. They may be considered almost distinctive in man, as they are not found in animals, and even our supposed forefathers—the monkeys—cannot lay claim to them.

THE EYELIDS.

The eyelids are two thin movable folds, placed in front of the eye to protect it from injury by their closure. The upper lid is much the larger and more movable of the two, while the lower one is almost stationary. The result from this difference in size is that when the eye is closed the pupil is completely covered by the upper lid, and is, therefore, much better protected than it would be if placed opposite the fissure between them. An additional protection is afforded during sleep, or when the eye is threatened with violence, by a rolling upward of the ball.

The skin of the eyelids contains no fat, which is a fortunate provision for stout people, for if fat increased there as it does sometimes in other parts of the body the eye would be mechanically closed by the sweiling and accumulation of adipose tissue.

This mechanical blindness may result from the swelling caused by injury or disease, an example of which is seen in erysipelas of the face and in rhus poisoning affecting this portion of the body.

The eyelids consist principally of plates of cartilage, called the tarsal cartilages, which afford the necessary support and maintain their shape. These are covered on the outside by a loose thin skin and lined with a smooth and delicate mucous membrane, called the conjunctiva; in addition to which are the muscles that move the eyelids.

The lids lie gently upon the eye and are maintained in accurate contact with it by atmospheric pressure. The two surfaces—that is, the outer surface of the eye and the inner surface of the lid—move upon each other with perfect freedom and with an entire unconsciousness of friction in health, but which is quickly disturbed by the presence of the smallest particle of dust. This absence of friction depends not only upon the smoothness of the surfaces and their exquisite adaptation to each other, but because they are lubricated by a secretion of mucus from the conjunctiva and moistened by a constant flow of tears.

The polish and transparency of the cornea are preserved by frequent unconscious winking, which keeps its surface moist and free from dust. When the lids cannot be closed, because of paralysis of the muscle, the cornea soon becomes hazy and dim, from the evaporation of the fluid from its surface, and blindness may be the result.

There are a number of small glands, about thirty in number, called the *meibomian glands,* situated upon the inner surface of the lids and which open upon their free margin near the roots of the lashes, and thus serve to keep the edges of the lids greased with an oily secretion, which not only prevents their adhesion, but also impedes the overflow of tears. This latter effect may be seen by greasing the edges of a cup and then filling it with water, when it will be found that the surface of the water can be raised to a higher level than the edges of the cup, or, in other words, there will be no overflow in the greased cup with the same amount of water that quickly overflows a cup that has not been greased.

EYELASHES.

When the lids are partially closed the lashes come together in such a way as to form a kind of a screen, which, without excluding vision, serves as an admirable protection against wind and dust and excessive light. As their bulbs are freely supplied with nerves, they are delicately sensitive to the slightest touch, and act as "feelers" to warn the eye of the approach of any small object, as an insect in the dark or when the vision is not on guard.

Each eyelash reaches its maturity in about five months and then drops out and is succeeded by a new one. This process is greatly interfered with by inflammation of the edges of the lids, when the lashes come out more freely and are not renewed again, or if restored, the new lashes take a wrong direction and turn their points against the surface of the eyeball. This is the condition known as "wild hairs"; it causes much discomfort and leads to serious damage to the sight by clouding the cornea. When the lashes are lost entirely, the face has a peculiar and unnatural appearance.

THE CONJUNCTIVA.

The mucous membrane of the eye is called the conjunctiva; it is continuous with the skin at the margin of the lids; it lines their inner surface (*palpebral conjunctiva*) and then passes over to the ball, forming a loose fold. It covers the front part of the sclerotic (*ocular conjunctiva*) and lines the walls of the tear ducts, becoming continuous with the mucous membrane of the nose and throat, and hence they are all affected in "a cold in the head" or influenza.

The conjunctiva is ordinarily transparent, with perhaps a few of the larger blood-vessels seen winding through it, but it quickly becomes red and congested from local injury or inflammation, or by disturbances of the circulation of the head, as in the case of the blood-shot eye in the morning that tells of the previous night's debauch.

The conjunctiva is the seat of many of the ordinary inflammations of the eye, usually termed "sore eyes," and of that intractable disease known as "granulated lids." The characteristic yellow tinge of the eye in jaundice is due to the coloring matter of the bile being deposited in this membrane.

The conjunctiva is the lodging place of foreign bodies that so frequently get into the eye and cause so much irritation. Some of them become imbedded in its tissues and have to be forcibly removed. Others drift along in the current of tears and lodge at the inner canthus, where they can be easily extracted. Sometimes it becomes necessary to evert the upper lid in order to discover the offending particle.

The *apparent size* of the eye depends chiefly upon the width of the opening between the lids. The actual size of the ball varies but little in different individuals, but some eyes appear much larger than others because the lids are more widely separated. When an inflamed eye is kept constantly partially closed from an excessive sensitiveness to light, much anxiety is often caused by the fear that it is becoming smaller.

A drooping eyelid conveys the impression of weakness or fatigue, and in the final stages of wasting fevers the half-closed eye, concealing the cornea and exposing only the white sclerotic, has a ghastly effect, and is considered a most discouraging symptom.

THE LACHRYMAL APPARATUS.

By the lachrymal apparatus is understood that series of structures which has to do with the manufacture of tears and the disposition of them by drainage into the nose. It consists of the lachrymal gland which secretes the tears, and the ducts which convey the fluid to the eye, which, after washing its surface, is collected and carried away by the lachrymal canals into the lachrymal sac and thence along the nasal duct into the cavity of the nose.

The lachrymal gland is located in a depression in the roof of the orbit at its upper and outer part. It is oval in form, about the size and shape of an almond. Its secretion is poured upon the ball through a number of small ducts, from seven to ten in number, which open by small orifices on the upper and outer half of the conjunctiva, the openings being arranged in a row, so as to disperse the secretion over the surface of the eye.

Under ordinary circumstances the tears are supplied in the usual quantities, but under the stimulus of emotion or a foreign body in the eye they are poured forth in large quantities. The direction of the flow of tears is from above and outward, downward and inward. At the inner corner of the eye they drain into the lachrymal points (one on each lid), the canals from which converge into the lachrymal sac, which merges into the nasal duct, and passes into the nose. Ordinarily we are not conscious of any moisture in the nose; but when there is a hypersecretion of tears we have a "running of the nose" and an overflow on the cheek.

It is a curious fact that infants do not shed tears before the third or fourth month; and among the lower animals the elephant is the only one accused of this human weakness.

MUSCLES OF THE EYEBALL.

The eyeball is moved in various directions by the muscles of the eye, six in number—four straight and two oblique muscles—as follows:

External Rectus Muscle.
Internal Rectus Muscle.
Superior Rectus Muscle.
Inferior Rectus Muscle.
Superior Oblique Muscle.
Inferior Oblique Muscle.

The superior rectus muscle is attached to the upper portion of the globe and moves it in an upward direction; the inferior rectus to the lower portion, and moves it downward; the external rectus to the outer portion, and moves it outward; the internal rectus to the inner portion, and moves it inward. The superior and inferior oblique muscles are attached to the outer portion of the ball, and move it in a rotary or oblique manner.

The external rectus is supplied by the *sixth* cranial nerve, the superior oblique by the *fourth nerve,* and the remaining four motor muscles, as well as the levator palpebræ superioris, by the *third* nerve.

A shortening or contraction of one of these muscles causes the condition of strabismus or cross-eye. If the internal rectus muscle is affected, the eye turns in and convergent strabismus is the result. If the external rectus is affected, the eye turns out, and divergent strabismus results. Sometimes these conditions can be cured by glasses; at other times only by the division of the offending muscle by the surgeon's knife.

WHAT A WONDERFUL ORGAN.

With the foregoing knowledge of the anatomy of the eye, the student can appreciate what a wonderful organ it is and how admirably adapted for the purpose it is intended to serve. The sense of sight is the most remarkable of all our senses, both for the special nature of the impressions which it receives, the complicated structure of its apparatus, and the variety and value of the information which it affords with regard to external objects.

It is by this sense that we receive the impressions of light and color, with all their modifications of intensity and combination, and acquire our principal ideas of form, space and movement. The eye is also superior to the other organs of special sense in the rapidity of its action and in the delicacy of the distinction which it is capable of making in the physical qualities of external objects; and it affords the most continuous and indispensable aid for all the ordinary occupations of life.

CHAPTER III.

THE EYE OPTICALLY; OR, THE PHYSIOLOGY OF VISION.

The eye is certainly the most useful, as it is the most wonderful, of all our organs of special sense. The organs of touch, taste and smell, in order to perform their functions must be placed in actual contact with the foreign substances which excite their activity; but the sense of sight is not so limited, but is equally sensitive to the impressions of light, whether it comes from an object close at hand or from the immeasurable distances of the fixed stars.

The eye is in more direct connection with the brain and mind than is any other organ, and thus it often expresses the strongest passions and the most tumultuous emotions, as well as the gentlest thoughts and most delicate sentiments. Much of this external intelligence that dwells in the eyes is marred in persons who squint or who are near-sighted. How often are we influenced in our judgment of the character of others, whom we meet for the first time, by the expressions of their eyes.

The cavity of the eyeball is like a room with but one window, where all the light which enters must come from the front and necessarily strikes the back wall of the apartment. The construction of the eyeball, in its general arrangement as an organ of vision, is very much like an optical instrument, and as such is subject to the same physical laws as govern any other optical instrument. Images of external objects are formed in the eye exactly as they are formed in a photographer's camera, where they fall upon a chemically sensitive plate and are made permanent by the chemical changes induced by light. In the eye they fall upon the nervously sensitive retina, and the impression they make is immediately conveyed to the brain by the fibres of the optic nerve, so that it is really not the eye that sees, but the brain, as it is only after the brain takes cognizance of the image that is formed in the eye that the visual act is complete.

The convex lens of the camera, which can be screwed in and out to receive clear images of objects at different distances, is represented in the eye by the crystalline lens, which has the faculty of changing its convexity and thus accommodating the eye for far and near distances. The blackened inner surface of the camera is represented by the choroid, which lines the whole inner surface of the sclerotic with a dark pigment and thus prevents reflections within the eye and absorbs the excess of light which has passed through the substance of the retina.

The conditions necessary for clear and satisfactory vision are as follows:

First.—A well-defined image must be formed on the retina at the yellow spot.

Second.—The impression there received must be conveyed quickly and directly to the brain.

To these a third may be added, viz., a mental projection into space of the sensation produced, or a referring of the impression outward in the same direction from which it came.

The optometrist is more particularly concerned in the first of these conditions, as it is his business to so correct existing optical defects as to make it possible for a distinct image to be formed upon the retina.

But if, after a perfect image is formed, the conducting power of the nerve is so much impaired as to be incapable of conveying the impression of the image to the brain, then the case passes beyond the province of the optometrist and requires treatment at the hands of the oculist.

If either the conducting function of the optic nerve or the perceptive function of the retina should be abolished, there would be no vision at all; but when the retina and optic nerve are healthy the quality of vision depends entirely upon the transparency of the refracting media and upon the perfection of the optical images which they form. Vision may therefore be imperfect either because the refracting media of the eye have lost their transparency or because the images cast upon the retina are blurred by some optical defect.

THE REFRACTING MEDIA.

The refracting media of the eye are the cornea, the aqueous humor, the crystalline lens and the vitreous humor.

The cornea is capable in a twofold manner of refracting and converging the rays of light that fall upon and traverse it; it affects them first by its density and in the second place by its convexity. After the ray of light has passed through the cornea it next traverses the aqueous humor, which humor affects the ray but very little, its chief use being to maintain the proper convexity of the cornea and at the same time to furnish a medium in which the movements of the iris can take place.

In regard to the vitreous, it may be said that its principal use appears to be to give the proper distention to the globe of the eyeball and also to keep the surface of the retina at the proper focal distance from the lens.

The *crystalline lens* is the most important refractory medium of the eye. It acts, by virtue of its double convex form, as a converging lens, bringing to a focus the luminous rays that pass through it.

Diagram A

The function of the crystalline lens is to produce distinct perception of form and outline. If the eye consisted merely of a sensitive retina covered by a transparent membrane, the impressions of light would be received, but would afford no idea of form or outline, producing merely the sensation of confused light, amounting simply to the perception of light from darkness. Such a condition is illustrated by the accompanying diagram.

The arrow represents a luminous body, while the vertical line at the right represents the retina. The rays which diverge from the point of the arrow reach every part of the retina, and in like manner the rays which diverge from the butt of the arrow reach every part of the retina; consequently, the different points of the retina each receive rays coming from both the point and butt of the arrow. There can, therefore, be no distinction by the retina between the point and the butt of the arrow and no definite perception of its figure.

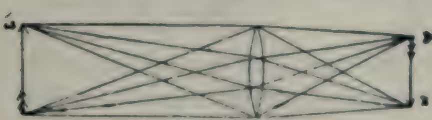


Diagram B

But if now there is supplied between the arrow and the retina a double convex lens of the proper focus, the effect will be entirely different, as shown in the accompanying diagram.

In this case all the rays emanating from the point of the arrow will be concentrated at one certain spot and all the rays emanating from the butt of the arrow at another certain spot. Hence the retina receives the impression of the point of the arrow separate and distinct from that of its butt; and all parts of the arrow will be separately and distinctly perceived.

From the foregoing figures it is easily seen that distinct perception of the form of an external object is only possible when all the rays of the light emanating from each and every point of the object are accurately focused on the retina by the crystalline lens of the eye. In order to accomplish this satisfactorily, the density of the lens, the curvature of its surfaces and its distance from the retina must all be in proper proportion to each other.

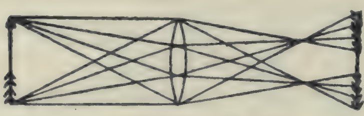


Diagram C

If the lens is too convex, or if it is too far from the retina, the rays would meet in focus before reaching the retina and would cross each other and fall upon the retina in diffusion circles, as is illustrated in the accompanying diagram.

The image from a case of excessive refraction, as shown above, would not be clear and distinct, but would be diffused and indistinct, because the rays of light, instead of being concentrated to a definite point, are dispersed more or less over the surface of the retina.

If, on the other hand, the lens is too flat, or if it is too near the retina, the image again would be confused and indistinct, as illustrated in the following diagram:

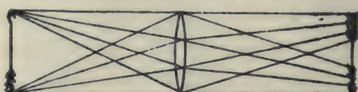


Diagram D

The image from a case of deficient refraction, as shown here, would not be clear and distinct, but would be diffused and indistinct, because the rays of light are dispersed more or less over the surface of the retina, instead of being concentrated to a definite point. In both of the above cases the rays of light strike the retina in diffusion circles without producing any well-defined image; in the first case, because they have actually converged and crossed each other, and in the second place, because they have only approximated but never converged to a focus.

These diagrams will serve to illustrate the conditions found in myopia and hypermetropia, respectively. In myopia the focus is in front of the retina; in hypermetropia the rays strike the retina before they have had an opportunity to meet in focus. In both cases the retina receives diffusion circles instead of distinct images.

INDEX OF REFRACTION.

Refraction of light depends upon its passage through media of different density with varying indices of refraction. Therefore, the optical student is interested in these values as stated in the following table:

Air (standard)	1.00
Water	1.33
Crown Glass	1.50
Flint Glass	1.60
Cornea	1.33
Aqueous Humor	1.33
Vitrous Humor	1.33
Crystallne Lens-Cortex	1.40
" " intermediate layer	1.42
" " nucleus	1.43
Crystalline Lens (as a whole)	1.4371

The refraction of rays of light entering the eye is as follows: Passing from air (1.00) into the cornea (1.33), they are converged; then, continuing into the aqueous humor, which has the same index (1.33) and may be considered a continuation of the cornea. Passing into the crystalline (1.43), which is of higher index, the rays are still more converged, but not as much as at the cornea, because the difference between the aqueous (1.33) and the crystalline (1.43) is not as great as between air (1.00) and the cornea (1.33). Passing then from the more refractive crystalline to the less refractive vitreous, but through a surface convex towards the less refractive medium, the rays suffer still more convergence, after which they proceed through the vitreous to focus on the retina.

Referring to the refraction of light by the crystalline lens, it is to be noted that it is not simply a matter of refraction by its anterior and posterior surfaces, but there is a variation of the index of refraction from layer to layer, causing light to be refracted in accordance with the variations of refractive index, being always towards greater convergence, because the layers are all convex towards least refracting medium.

The total refractive power of the emmetropic eye is about fifty-eight diopters, made up principally of the cornea and crystalline lens, as follows:

Cornea	43 D.
Crystalline lens	15 D.
Total	58 D.

This means that the focal length of the refracting system of the eye is seven-tenths of an inch, or thereabouts. The reader will be able to form some conception of the great power of refraction the eye possesses when he considers that the strongest convex lens in the trial case is 20 D. and that the eye is almost three times as powerful.

RADIUS OF CURVATURE

Of anterior surface of cornea	7.8 mm.
Of anterior surface of crystalline lens when the ciliary muscle is at rest	10 mm.
Of posterior surface of crystalline lens	6

FORMATION OF IMAGE ON RETINA.

As has been stated, the rays of light, after being converged by the crystalline lens, form their image upon the retina, which, consequently, is the most essential part of the organ of vision, as it is the only one of its tissues directly sensitive to light. The retina is a delicate, transparent membrane, composed largely of nervous elements and lining the whole interior of the cavity of the eyeball. The retina seems to be a continuation of the optic nerve, which enters the eyeball by piercing the outer coats and spreads out to form this membrane. It has been found by microscopists to consist of a number of different layers, which together form this membrane, the whole being connected with the extremities of the optic nerve fibres.

On account of the delicate nervous structure of the retina, it is well adapted to receive the impressions of the rays of light, and by means of its intimate connection with the optic nerve, to convey such impressions to the brain.

All parts of the retina are not equally sensitive to light, there is one portion, called the *yellow spot*, or *macula lutea*, that is more sensitive than any other part. In fact, it is the only spot on the whole retina that affords clear and perfect vision, while vision becomes gradually more and more imperfect as the image is impressed upon the retina farther and farther from this yellow spot. Consequently, it becomes necessary in reading to move the eyes backward and forward along the lines of the print, so as to bring each word of every line and each letter of every word in the direct line of vision, in order that its image may fall upon this sensitive yellow spot.

So in distant vision, the eyes must be in continuous, though unconscious, motion, in order that the different objects around us may be placed in such a position, in reference to the eye, that their images may again fall upon this sensitive yellow spot. An active, sprightly person moves his eyes quickly from object to object, so as to see everything clearly by bringing everything into a direct line of vision with this yellow spot, while dull, phlegmatic people are satisfied with a general view of things as their images may happen to fall upon any part of the retina without taking the trouble to move their eyes and adjust their accommodation, so that the same images may be sharply focused upon the yellow spot.

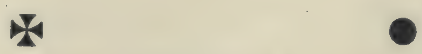
THE BLIND SPOT.

In contrast with and very near to this sensitive yellow spot, there is a small spot that is insensible to the rays of light, which means that it is a blind spot. At first thought it seems somewhat strange that there should be a blind spot in every man's eye, and also that this spot of least vision, or blind spot, should be so near to the spot of best vision, or yellow spot. But this is the case, and a still more curious fact is that this blind spot is just at the entrance of the optic nerve, where it would naturally be thought that vision ought to be the most acute. The explanation of this is that the nerve fibres here belong to the conducting layer of the retina, while the percipient layer is wanting at this point.

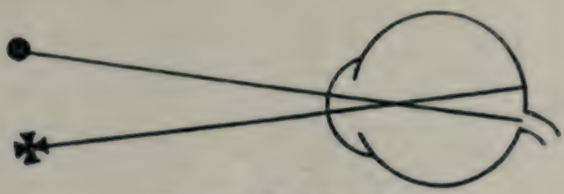
It would seem reasonable to suppose that if there is a blind spot in every one's eye there ought to be a corresponding dark spot in the field of vision Such is not the case, for the following reasons: When the eye is directed toward any object, to see, the image falls upon the yellow spot, which is in the visual axis of the eye, while the blind spot is situated a little to the inner side of this point. Consequently, the image of an object which is directly examined in the normal line of vision cannot fall upon this blind spot.

When both eyes are open an object may be so placed that its image falls upon the blind spot of one eye, in which case, however, it will necessarily fall upon the yellow spot of the other eye, and the object be distinctly seen. It is impossible for an object to be placed in such a position that its image could fall upon the blind spot of both eyes at the same time.

If, however, only one eye is used, there is always a small portion of the field of vision that is imperceptible. This deficiency is not noticeable, because it is located in a part of the field of vision to which our attention is scarcely directed and where the perception of various objects is so imperfect that the momentary absence of one of them is not regarded. That this blind spot does exist can be readily made apparent and any one can observe it for himself by using for the test a single strongly defined object, like a white spot on a black ground, or a black spot on a white ground, the presence or absence of which may be quickly noticed.



The left eye is to be closed and the right eye to be directed steadily at the cross on the left-hand side of the illustration; the round spot will also be visible, though less distinct than the cross, because it is not in the line of direct vision. Let the page be held vertically before the eyes and at a convenient distance for seeing both objects in the manner just mentioned. If it now be moved slowly backward and forward a point will be found at a certain distance, about ten or twelve inches, where the circular spot disappears from view, because its image has fallen upon the optic nerve entrance, or blind spot, which is insensible to the rays of light, to reappear again if the paper be moved nearer or farther. It may also be made to reappear, even at the same distance, by inclining the page laterally to the right or left, since this would bring the circular spot either above or below the level of the blind spot. The phenomenon of the blind spot is well illustrated in the following figure:



Illustrating Blind Spot Test.

THE FIELD OF VISION.

As a man looks out upon a landscape, there is in front of each eye a circular space within which objects are distinctly perceptible, while beyond its borders vision fades away to nothingness. This circular space is called "the field of vision." In man it has quite a large limit; for instance, when the eye is directed straight forward, the light from a brilliant object may be perceived when the object itself is placed away around to one side. In many of the lower animals, where the eyes are more prominent than in man, the field of vision is very much enlarged. In birds and fishes it is still further enlarged by the lateral position of the two eyes. The ostrich, when its head is directed forward, can easily see objects placed a few yards behind its back; the field of vision for such an animal is consequently a complete sphere, objects being perceptible in every direction.

In man the field is limited, and objects placed laterally at the external borders of the field must be very brilliant to attract attention. Within this field there is only one point where objects can be seen with perfect distinctness; it is in the center of the field, and its prolongation forward from the pupil is called the "line of direct vision." Objects met with upon this line can be distinctly seen; all other objects, situated on either side, above or below it, are seen more or less imperfectly. If one places himself in front of a fence composed of vertical stakes he can see those placed directly in front of the eye with perfect distinctness, while those on either side begin to appear uncertain and confused. On looking at the center of a printed page in the line of direct vision we can see the distinct outlines of the letters, while at successive distances from this point, as the eye remains fixed, we distinguish at first only the separate letters with confused outlines, then only the words, and lastly only the lines and spaces.

This limitation of distinct sight to the line of direct vision is practically compensated for by the great mobility of the eyeball, which rapidly turns in all directions, thus shifting the line of direct vision and examining in turn every part of the field of vision attainable by the eye. In reading this page the eye follows the lines from left to right, seeing each letter and word distinctly in succession. At the end of each line it returns, suddenly, to the commencement of the next, repeating the same movement from the top to the bottom of the page.

The cause of the indistinctness of the images seen outside the line of direct vision is a twofold one; first, because the rays of light, on account of the oblique manner in which they enter the eye, are more rapidly converged, and consequently are not accurately focused upon the retina; in the second place, a perfect image is impossible, on account of the diminished acuteness of the retinal sensibility at every part of the retina except at the yellow spot.

In the formation of well-defined images on the retina to the end that perfect vision may result, there are three factors involved, as follows: *Refraction, Accommodation, Convergence.*

REFRACTION.

Distinct vision necessarily depends upon the rays of light which enter the eye, being brought to an accurate focus upon the retina. The refracting media of the eye are the cornea, the aqueous humor, the lens and the vitreous humor, which, taken collectively, may be regarded as forming a single lens, having equal refraction in every meridian, the focal length of which is precisely equal to the length of the axis of the eyeball. The normal human eye may be defined as an optical apparatus of such form that parallel rays of light—that is, rays proceeding from a distance of twenty feet or more—are precisely focused upon the retina without any effort upon the part of the eye, thus imprinting upon this sensitive membrane a sharply defined image of all objects from which these rays emanate. This is the condition known as *emmetropia,* this word being derived from two Greek words signifying that it is in measure.

As the emmetropic eye is the optometrist's ideal, it is well that the student should be familiar with this condition, in order that he should be able to quickly recognize any departure from it.

The standard eye has an antero-posterior diameter of about twenty-three millimeters; its nodal point is seven millimeters back of the cornea and fifteen millimeters in front of the retina. thus allowing one millimeter for thickness of sclerotic and choroid.

The fovea, or yellow spot, of the emmetropic eye is situated exactly at the principal focal distance of its refracting system, and its vision in a state of rest is adapted for infinity. The various departures of the eye from emmetropia are called *errors of refraction.*

AMETROPIA.

When this normal condition is departed from in any direction, then we have the condition known as *ametropia,* signifying that it is out of measure. This departure from the normal condition may be in three different directions.

In one case the eyeball may be flattened from before backward, in which case the rays of light, instead of being focused upon the retina, do not come to a focus until they get behind this membrane; this state of affairs constituting the condition known as *hypermetropia.*

In another case the eyeball may be elongated from before backward, in which case the rays of light, instead of being focused upon the retina, come to a focus before they reach this membrane, thus constituting the condition known as *myopia.*

Either of these departures from the emmetropic condition may exist from a very small degree to a very great degree.

This figure illustrates very graphically the extremes of hypermetropia and myopia as compared with emmetropia, having been taken from actual measurements of defective eyes:

Diagram showing an emmetropic eye as compared with an extremely hypermetropic and an extremely myopic eye.

In another case the curvature of some one of the meridians of the cornea of the eye may be flattened or elongated, thus causing the different rays to meet at different focuses, and constituting the condition known as *astigmatism.*

In all three of the above mentioned cases the result is the formation of indistinct images upon the retina and an inevitable impairment of vision.

As indicated above, there are two forms of ametropia: axial and curvature.

Axial ametropia is the condition in which refraction is equal in all meridians, but the retina, when the eye is at rest, is either closer to or farther from the nodal point than the principal focus; in other words, an increase or diminution of the length of the antero-posterior axis of the eye—hence its name. This is illustrated in hypermetropia and myopia, as mentioned above.

Curvature ametropia is that condition in which the curvature of the refracting media is not the same in all meridians, with the result that the rays entering the eye do not focus at any one single point, but instead there are two foci, one for the meridian of least and the other of greatest refraction. This is the condition found in *astigmatism.*

REFRACTION OF THE EYE.

This action of the eye upon light is called its *refraction,* the above illustrations referring only to parallel rays of light or those proceeding from a distance of twenty feet or more.

If the eye was a rigid organ and had no inherent power of its own to act on the rays of light received within it, it is evident that its refraction of light would always be the same: in emmetropia parallel rays would always be focused upon the retina; in hypermetropia the similar rays would always be focused behind the retina (we say behind the retina because that would be their focal point if they could pass through the membranes of the eye); in myopia similar rays meet in focus in front of the retina.

Refraction (this definition is repeated because every optometrist should clearly understand what it means) is the action of the eye on light when the eye is passive or at rest; that is, when it is not called upon to exert any power of its own to assist in bringing the rays of light to a focus. And consequently, when the refraction of the eye is referred to there is meant to be expressed that the eye when in a state of rest is either emmetropic, hypermetropic or myopic.

In the two latter cases, as can be easily understood by a reference to the figure given above, the rays of light that fall upon the retina can not produce clear or well-defined images of objects, but vision is blurred and indistinct. In myopia the rays fall upon the retina after having come to a focus and then overcrossed; in hypermetropia the rays have not yet come to a focus and fall upon the retina in this ununited condition. In both cases the retina receives only a patch of light (technically called a diffusion circle), instead of the defined image which is absolutely essential to satisfactory vision.

The term *static refraction* is sometimes used to describe the condition just explained, where the ciliary muscle is completely relaxed. And the term *dynamic refraction* to describe the condition when the ciliary muscle is in action, as in the function of accommodation. But unless expressly stated, the use of the term refraction of the eye indicates the static refraction.

HOW OPTICAL DEFECTS ARE CORRECTED.

As will be shown in the chapter on lenses, the property of convex lenses is to render parallel rays of light convergent, and the property of concave lenses is to render parallel rays divergent. If, now, these properties of convex and concave lenses are made applicable to the correction of the defects of the eye, the optometrist can readily understand that a convex lens placed before a hypermetropic eye brings the rays of light to an earlier focus, and if the convex lens is of the proper strength to correspond to the degree of the hypermetropia, then the focus of the rays of light will be brought so far forward as to exactly correspond to the retina and will, therefore, be focused upon the retina.

If, on the other hand, a concave lens be placed before a myopic eye, the rays of light are made divergent, and thus made to come to a later focus; and if the concave lens is of the exact strength to correspond to the degree of the myopia, then the focus of the rays of light is thrown so far back as to correspond to the position of the retina, and the focus will, therefore, fall upon the retina. If the above statements are carefully considered, it can readily be seen how these optical defects can be corrected by the adjustment of the proper glasses.

The degree of the myopia or hypermetropia is expressed by the strength of the lens required to correct it. A hypermetropia of one dioptric is one that requires a convex lens of one dioptric (+ 1 D.) to correct it; a myopia of two dioptrics is one that requires a concave lens of two dioptrics (— 2 D.) to correct it.

In addition to these defects, there is a third one, which has already been mentioned as astigmatism, in which one of the meridians of the eye is normal, while the meridian at right angles to it is either hypermetropic or myopic. Such an eye may be emmetropic for vertical lines and hypermetropic or myopic for horizontal lines, or *vice versa.* In such an eye the rays of light entering through its defective meridian are focused either before or behind the retina, while the rays entering through the emmetropic meridian are focused upon the retina; this confuses the sight and renders it more or less imperfect.

The test for astigmatism is that in looking at a card of radiating lines they are not all seen with equal distinctness, some being much clearer than others, while in extreme degrees of the defect some of the lines may be almost or altogether invisible.

It is well to know that the meridians of greatest and least curvature are always at right angles to each other. Astigmatism diminishes the acuteness of vision more or less markedly, and sometimes quite curiously; this is shown in the case of a man who consulted an oculist for what he called "periodical obscuration of vision," because he could see plainly the hands of the clock in his office at certain times of the day, while at other times he could scarcely see them at all. The oculist found that his peculiar vision was owing to astigmatism; that when the hands of the clock were in the meridian of good sight he could see them plainly, while when the hands had moved to the meridian of defective sight he could scarcely see them at all.

THE ACCOMMODATION OF OPTICAL INSTRUMENTS.

An optical instrument, composed of refracting lenses, can not be made to serve at the same time for near and far distances. In a refracting telescope or spy-glass, if the instrument be directed toward any part of the landscape, objects at a certain distance only are distinctly seen; all other objects, situated within or beyond this distance, are obscure or imperceptible. This is necessarily the case, since a lens or system of lenses can bring to a focus at one spot only those rays which strike its anterior surface with a certain degree of divergence. The formation of a visible image at the desired spot depends entirely upon the refracting power of the lenses being such that all the rays diverging from a particular point of the object shall be again brought to an exact focus at the plane where the image is to be perceived. If the object be placed at an indefinite distance near the horizon, or if it be one of the heavenly bodies, the rays emanating from any one point of such an object reach the telescope under so slight a degree of divergence that they are practically parallel, and on being refracted they will be brought to a focus at a short distance behind the lens.

But if the object be nearer, the rays emanating from it strike the lens under a higher degree of divergence. The same amount of refractive power in the instrument produces a less rapid convergence than in the former case, and the rays are consequently brought to a focus at a greater distance behind the lens. To provide for this difficulty, the spy-glass is constructed with a sliding tube, by which the distance of the eye-piece from the object glass may be changed at will. For the examination of remote objects the eye-piece is pushed forward so as to bring into view the image formed at a short distance behind the lens; for the examination of near objects it is drawn backward to receive the image placed farther to the rear. This is the accommodation of the spy-glass for vision at different distances.

PROOFS OF ACCOMMODATION.

A similar necessity (for distinct vision at different distances) exists in the optical apparatus of the eye. We have seen that the emmetropic eye in its passive condition (that is, when at rest and without making any effort) focused parallel rays of light exactly upon the retina. When, however, the rays proceed from objects nearer than twenty feet they are no longer parallel, but are then divergent, and consequently in this condition cannot be focused upon the retina unless there is some change in the refractive condition of the eye, because such rays require more converging than parallel rays in order to be focused at the same distance. The nearer an object approaches to the eyes, and consequently the more divergent the rays that proceed from it, the greater the amount of converging (and therefore the stronger the refracting lens) that will be required, provided it is desired to keep the focus at the same distance.

The eye must possess some means of increasing its refractive power in order that these divergent rays of light may still be sharply focused upon the retina, or else we would all be deprived of the pleasure of clear vision of close objects; because, as we have already seen, the distinctness of the image formed in the eye of the observer depends upon the rays of light being brought to a perfect focus upon the retina.

That the eye does possess such a power of variation of sight for different distances can be proven not only by reasoning, but by direct experiment. This is shown in the case of the emmetropic eye, by which objects situated at various distances from the eye can within a certain range be seen with almost equal distinctness; as, for instance, such an eye can read the large letters on a sign a hundred feet or more away, the letters being clear and distinct, and the next second the same eye can read a page of smallest type held a few inches from the eyes, the letters being equally as distinct as in the case of the sign one hundred feet away. If the type is brought closer to the eyes, the individual becomes conscious of a sense of effort which increases as the type gets nearer, until presently the type gets so near that the divergence of the rays proceeding from it can no longer be overcome, and then the letters become blurred; this shows that there must exist some provision by which the eye is enabled to adapt itself to vision at different distances, so that, whatever length the focal distance may be, the focal point may always fall exactly upon the retina.

An illustration of this adaptability of the eye that has been frequently used, but that is as good as it is old, is to stretch in front of the eye, at a distance of seven or eight inches, a plain gauze veil, or other woven fabric formed of fine threads with tolerably open meshes, so that objects beyond may be readily visible through its tissue. If this veil be held between the eye and a printed page (using only one eye) we can see at will either the threads of the veil or the letters on the printed page through the interstices of the veil, but we cannot distinctly see both at the same time. When we see the threads of the veil sharply defined, the printed page is so blurred and indistinct that we are conscious of it only as an indistinct background; and when we direct our attention to the letters so that they are clear and legible, the threads of the veil become almost imperceptible and seem but as an intervening film, which scarcely interferes by its presence with the reading. In order to see sharply either one or the other, we are conscious of a change which we involuntarily make in the adjustment of the eyes.

When a fly alights on a window-pane and our attention is attracted to it so that we see it clearly, the landscape beyond becomes indistinct and obscure; but when we look directly at the landscape so as to see its beauties, the fly on the pane becomes a shapeless spot.

THE ACCOMMODATION OF THE EYE.

It is evident, therefore, from the foregoing illustrations that the eye cannot perceive distinctly and at the same time objects which are situated at different distances, but that it must fix alternately the nearer and the more remote, and examine each in turn. It is also evident that in thus bringing alternately the one or the other object into distinct view, there must occur some change in the refractive power of the eye by which the sight is adapted to the distance or nearness of the object under examination.

The change which takes place as above described, or the power of variation and adjustment of the eye for vision at different distances, is known as the *Accommodation of the Eye*, and it is being constantly brought into requisition. The method by which the accommodation of the eye is effected forms one of the most important parts of the physiology of sight, and this power of adaptation of the eye to vision at different distances has received the most varied explanations.

It is obvious that the effect might be produced in one of two ways: by an alteration of the convexity or intensity of either the cornea or crystalline lens, thus changing their refractive power; or by changing the position of either the retina or lens, so that whether the object viewed be near or far, and the focal distance be diminished or increased, the focal point to which the rays are converged may always be at the place occupied by the retina. The amount of either of these changes required in even the widest range of vision is extremely small. It has been calculated that the difference between the focal distances of the images of an object at infinite distance and of one as close as four inches is only .143 of an inch.

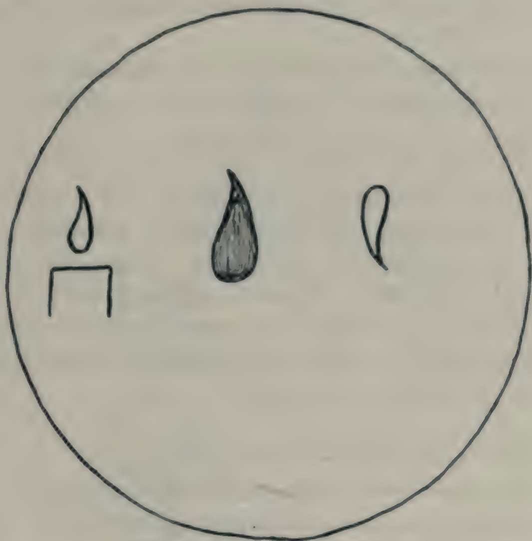
In considering this subject it is well to remember that accommodation for distant vision is a passive condition, requiring no effort on the part of the eye, while accommodation for near objects is the result of muscular effort. This fact is, to some extent, made apparent by the nature of the sensations accompanying the change. The eye rests without fatigue for an indefinite time upon remote objects, while for the examination of those close at hand a certain effort is necessary, and if it be prolonged, it, after a time, amounts to a sense of fatigue.

It may also be remarked in passing that a solution of atropia (the active principle of belladonna) when applied to the eye causes temporary paralysis of the sphincter muscle of the iris and consequent dilatation of the pupil, and suspends more or less completely the power of accommodation for near objects, while in emmetropic eyes distant vision remains undisturbed. Now, it naturally follows that if accommodation for far and near objects was in each case the result of muscular action, the atropia that paralyzes one would also certainly paralyze the other, in which case distant vision would be as much blurred as near vision. Another point that might be mentioned as corroborative proof in this direction is the diminution and loss of accommodative power that occurs in advanced life, when the accommodation for near objects becomes more and more deficient, while distant vision is but little if any affected.

It is now almost universally believed that the essential change upon which all the results of accommodation are directly dependent is due to a varying shape of the crystalline lens, its front surface becoming more or less convex according to the distance of the object looked at. The nearer the objects approach, the more convex does the front surface of the lens become, the back surface scarcely changing its shape and having but little or no share in the production of the effect required.

CHANGES IN CURVATURE OF CRYSTALLINE LENS DURING ACCOMMODATION.

Accommodation, then, depends upon an increase in the convexity of the crystalline lens, and this increased convexity occurs chiefly upon its anterior surface, and this point can be illustrated by a little experiment which any one can perform for himself. If in a darkened room a candle flame be held a little to one side of a person's eye so that its rays fall somewhat obliquely upon the cornea of the eye under observation, and at an angle of about thirty degrees with its line of sight, and if the observer will place himself on the opposite side at an equal angle with the line of sight, he will see three distinct reflected images of the candle flame.



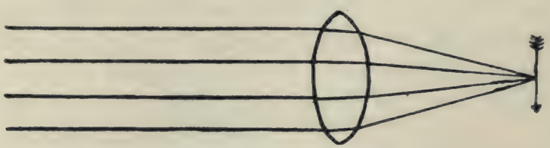
Candle Flame Images in Eye.

The first image, which is the brightest of all, is a small upright image reflected from the anterior convex surface of the cornea. The second image, which is also upright, but somewhat larger and less distinct than the first, and somewhat difficult to find, is the reflection from the anterior convex surface of the lens. The third image is tolerably distinct, but smaller and inverted, and is the reflection from the posterior surface of the lens acting as a concave mirror, and therefore, like all concave mirrors, giving a reversed image.

If the eye under observation be now made to change its point of sight from a distant to a near object, the position of the eyeball remaining fixed, the middle image becomes smaller and clearer and approaches the first one.

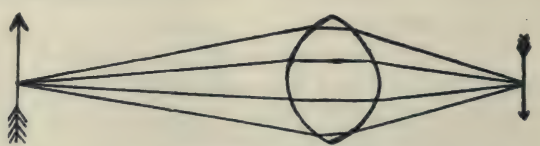
This experiment of the candle flame images, in which the middle image changes its appearance and position when the eye changes its point of observation, proves that during accommodation for near objects the anterior surface of the lens, from which this second image is reflected, becomes more bulging and approaches the cornea, while the curvature of the cornea and the posterior surface of the lens remain unchanged. The advance of the iris and pupil, in consequence of the protrusion of the anterior surface of the lens, can also be observed directly by looking into the eye from the side.

The accommodation of the eye for near objects is, therefore, produced by an increased refractive power of the lens, from its increased convexity or from the greater bulging of its anterior surface. This has the effect of increasing the rapidity of the convergence of the rays passing through it, and consequently compensates for their greater divergence before entering its substance. In the ordinary condition of ocular repose, when the eye is directed to distant objects, the rays coming from any point of such objects arrive at the cornea in a nearly parallel condition, and are then focused by the refractive media of the eye on the retina, as is shown in the following figure:



Vision for Distant Objects.

If now the eye be directed to a near point and the accommodation thus be called into play, the crystalline lens increases its anterior convexity, and by this means the divergent rays proceeding from the near object are more strongly refracted, and are still brought to a focus on the retina as before, as is shown in the following figure:



Vision for Near Objects.

It thus becomes possible to fix alternately in distinct vision objects at various distances in front of the eye.

THE MECHANISM OF ACCOMMODATION.

Of course, the crystalline lens has no inherent power of its own to contract, and therefore its changes in shape must be produced by some power from without; this power is supplied by the ciliary muscle, although it was formerly thought that the iris and the external ocular muscles assisted in the change of the adjustment of the eye.

This ciliary muscle that produces the change, on account of its function, is called the muscle of accommodation, and the manner in which this muscle acts to produce these changes is somewhat as follows:

The act of accommodation has been shown to depend upon an increase in the convexity, and hence also in the refractive power, of the crystalline lens. The lens, which has a certain innate elasticity, is kept partly flattened by the action of the suspensory ligament on the capsule of the lens; the ciliary muscle has such attachments that when it contracts the tension of the ligament and of the capsule is relaxed and diminished to a proportionate degree; the pressure being thus removed, the lens tends to assume its naturally more convex form. On the diminution or cessation of the action of the ciliary muscle, the lens returns in a corresponding degree to its former flattened shape by virtue of the elasticity of its suspensory ligament. Thus it appears that the eye is usually and naturally focused for distant objects.

This is the famous *Helmholtz theory of accommodation*, and while it is not the only one advanced, it is the one that is most generally accepted. The next best known theory is that worked out by Tscherning, who claims that accommodation is produced by increased tension of the suspensory ligament and not by its relaxation; or, in other words, that the lens is stretched when we accommodate for a near point and relaxed in distant vision.

In connection with this increase of the convexity of the lens in near vision there occurs a corresponding contraction of the pupil, dilatation of the same taking place when the attention is withdrawn from near objects and fixed on those at a distance.

Our present more or less complete knowledge of the accommodation of the eye and of the mechanism by which it is accomplished, simple as it now seems to us, has been arrived at only after an immense amount of laborious work and patient research, one physiologist after another finding out and recording some new point bearing on the subject, until the master minds of Cramer and Helmholtz, utilizing the recorded results of past investigations and adding others of their own, finally developed the whole subject into the character of an exact science.

The effect produced by the effort of accommodation is exactly the same as would be produced by the placing of an additional convex lens within the eye.

Accommodation is an involuntary act, and when we look at near objects it occurs almost without our consciousness, and yet it is none the less the effect of muscular effort; hence the relief that often follows from looking up and away from near work, and this is especially grateful to fatigued and sensitive eyes

When the ciliary muscle has contracted as much as it can, and the lens assumed the greatest convexity possible, then the maximum amount of accommodation is in force and the eye is adjusted for its near point. In every eye there is a limit to the power of accommodation; that is, there is a limit to the convexity which the lens is capable of assuming; and when this limit is reached a closer approximation of the object necessarily destroys the accuracy of its image. This is evidenced in the case of a book which is brought nearer and nearer to the eye, until at last the type becomes indistinct and cannot be brought into focus by any effort of accommodation, however strong.

DETERMINATION OF THE NEAR POINT OF ACCOMMODATION

The near point of distinct vision is usually determined by placing in the patient's hand the small test type and noting the closest point at which it is possible for him to read it with each eye, separately.

A more accurate and scientific test for determining the near point is as follows: Two small holes, not more than a line apart are pricked in a card with a pin, and it is important that their distance from each other should not exceed the diameter of the pupil. The card is held close in front of the eye and a small needle view through the pin holes. At a moderate distance it can be clearly focused, but when brought nearer than a certain point the needle appears blurred and sometimes double. The point where the needle ceases to appear clear and single is the near point. Its distance from the eye can, of course, be readily measured. In ordinary normal eyes during the early or middle periods of life, accommodation fails and vision becomes indistinct when the object is placed nearer than five or six inches from the eye. Between the limits of five inches and infinite distance the amount of accommodation required varies with the distance, but not by any means in simple proportion to the variation of the distance. For instance, the change of accommodation necessary to clearly see objects situated respectively at six and twelve inches is much greater than that required for the respective distances of twelve inches and twenty-four inches. The farther the object is situated from the eye, the less difference is produced in the appreciable divergence of the rays proceeding from it by any additional increase of distance; and consequently less variation is required in the refractive condition of the eye to preserve the acccuracy of the image.

It has been generally found that no very sensible effort of accommodation is required for objects situated at any distance beyond twenty feet from the observer, while within this distance the amount of accommodation necessary to preserve distinct vision increases rapidly as the object approaches the eye.

RANGE OF ACCOMMODATION.

An eye which is capable of accommodating for distinct vision throughout the whole range included between five inches and infinite distance is in this respect a normal eye, and is said to be emmetropic.

When the muscle of accommodation has relaxed to its utmost and the lens assumed the least convexity possible, then the minimum amount of accommodation is in force and the eye is adjusted for its far point. In this condition the eye is said to be in a state of repose. In the emmetropic eye the far point is situated at infinity; but for practical purposes in determining the accommodation we measure it in inches by noting the farthest distance at which it is possible for the person to read the small test type with each eye separately.

The distance between the near point and the far point is called the *range of accommodation.*

AMPLITUDE OF ACCOMMODATION.

As age advances, the elasticity of the lens diminishes, the muscle of accommodation loses power, the range of accommodation is restricted, and the near point naturally and gradually recedes from the eye. Observation shows that these changes commence at a very early age, even in childhood. Infants often examine minute objects at very short distances. in a manner which would be quite impracticable for the adult eye. As the changes mentioned above continue to increase, the time arrives, between the ages of forty and fifty years, when the incapacity of accommodation for near objects begins to interfere with the ordinary occupations of life; when this occurs the eye is said to be presbyopic. The vision is still perfect for distance, but it can no longer adapt itself for the examination of objects close at hand. The remedy for this (as will be fully explained when we come to presbyopia) is a convex lens in the form of spectacles, to supply the deficiency in the convexity of the lens of the eye.

The following table gives the amplitude of accommodation at different ages:

10 years	14. D.	45 years	3.50 D.
15 "	12. D.	50 "	2.50 D.
20 "	10. D.	55 "	1.75 D.
25 "	8.50 D.	60 "	1. D.
30 "	7. D.	65 "	.75 D.
35 "	5.50 D.	70 "	.25 D.
40 "	4.50 D.	75 "	00

The claim is made by some authorities that unequal effort of accommodation of the two eyes is possible; in other words, that one eye can accommodate more than the other. Experiments with the stereoscope seem to prove, however, that accommodation is equal in the two eyes.

It is also held by some writers that accommodation may vary in different meridians, the so-called astigmatic accommodation, the effort being greater in the defective meridian so as to neutralize the astigmatism and equalize the meridians. This has been denied by other investigators, leaving the matter at the present time an open question.

In spite of the changes in the shape of the lens and the lengthening of its axis, there is no increase in its volume.

The emmetropic eye requires 4 D. of accommodation at ten inches. An eye having 2 D. of hypermetropia would require 6 D. of accommodation at same distance, while an eye with a myopia of 2 D. would need only 2 D. of accommodation.

1 D. of accommodation is required to change the adaptation of an emmetropic eye from infinity to a distance of one meter, or forty inches; 2 D. to adapt it to twenty inches, 3 D. for thirteen inches, and 4 D. for ten inches. It is thus shown that as an object approaches the eye the amount of accommodation necessary to afford distinct vision grows greater at a rapidly increasing rate.

Another point to be noted is that the addition of each diopter of accommodation calls for a greater effort than that of the preceding diopter.

RESERVE ACCOMMODATION.

It is not possible for any length of time to use all the accommodation; not more than two-thirds of the amount can be used continuously, in order to avoid overtaxing this function. A person having 4.50 D. of accommodation could not read comfortably at nine inches, at which distance all of the accommodation would be required; but he should hold one-third of his amplitude of accommodation (1.50 D.) in reserve, allowing 3 D. for continuous use, which would call for a reading distance of thirteen inches.

CONVERGENCE.

Convergence is the act of directing the visual axes of the two eyes to the same point at some near distance, and it is accomplished by the action of the internal straight muscles. The act of convergence is intimately associated with the act of accommodation, so that for every increase of the convergence there is a corresponding increase of the accommodation.

The object of convergence is the directing of the yellow spot of each eye toward the same point, so that the rays from any one point may strike the same portion of the retina of each eye, producing a similar image on corresponding portions of the two retinæ, and thus resulting in singleness of vision. This simultaneous use of both eyes is called "binocular vision," and in order that it may be pleasant and satisfactory, the eyes should have the same refraction and the same acuteness of vision, and both must be properly directed to the same object. There is then an image carried to the brain by each optic nerve; but as the images are formed on corresponding parts of the two retinæ, and as they are exact reproduction—one of the other—they are so combined by the brain as to give the impression of a single object. The advantages of binocular vision are the appreciation of solidity and the accurate determination of distance.

Double vision at once results when the image of an object is formed on parts of the retinæ which do not exactly correspond in the two eyes, because then the two images are so dissimilar that the brain is unable to fuse them into one.

The nearer an object approaches to the eyes, the more strongly must they be converged, and the more the accommodation must be brought into play. Hence, in converging our eyes to any one particular point, we, at the same time, also involuntarily accommodate for the same point, as the convergence muscles (the internal recti muscles) and the accommodation muscle (the ciliary muscle) act in unison.

ACTION OF PRISMS ON CONVERGENCE.

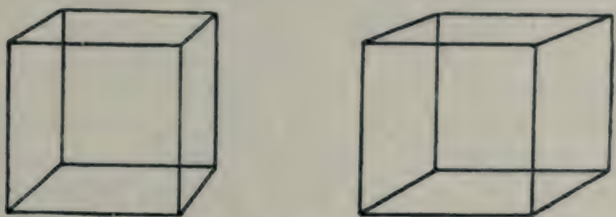
In order to test the power of convergence, prisms are used, and are placed before the eyes with their bases outward. The strongest prism which it is possible for the eyes to overcome—that is, the highest degree prism which does not produce diplopia on looking through it at a distant object (such as a candle flame, which is the best object to use for such a test)—is the measure of the strength of the convergence. This varies in different persons, usually ranging between twenty degrees and thirty degrees—that is, a prism of from ten degrees to fifteen degrees may be placed before each eye with their bases outward, and the strength of the convergence is sufficient to overcome the prisms and preserve singleness of vision.

Prisms placed before the eyes with their bases in assist convergence, and this fact is often made use of in the correction of those cases of asthenopia due to an insufficiency of the internal recti muscles.

When both eyes are directed simultaneously at a single point, as is the case in binocular vision, the distance of the object may be estimated with considerable accuracy by the degree of convergence of the visual axes required for its fixation. Since the degree of convergence required is in proportion to the proximity of the point of fixation to the observer, another impression of different kind, but of equal importance, is also produced by binocular vision, when the object has an appreciable volume and thickness and when it is placed within a moderate distance.

BINOCULAR VISION.

Owing to the lateral separation of the two eyes and the convergent direction of their visual axes, they do not both receive from the object precisely the same image. Both eyes will see the front of the object in nearly the same manner, but, in addition, the right eye will see a little of its right side and the left eye will see a little of its left side. This is illustrated in the following figure, which represents an outline cube:



2 1

Illustrating the difference between the images seen by each eye separately.

If this cube be held at a moderate distance before the eyes and viewed with each eye successively while the head is kept perfectly steady, No. 1 will be the picture presented to the right eye and No. 2 that seen by the left eye.

As the central part of the object is in the point of fixation at the junction of the two visual axes, the object appears single. But the images which it presents to the two eyes, as is shown in the figure above, are not precisely identical in form; and on this circumstance depends, in a great measure, our conviction of the solidity of an object, or of its projection in relief; that is, it is the combination of these two different images into one which gives rise to the impression of solidity.

If different perspective drawings of a solid body, one representing the image seen by the right eye and the other that seen by the left (as in the above illustration), be presented to corresponding parts of the two retinæ, as may be readily done by means of the stereoscope, the mind will perceive not merely a single representation of the object, but a body projecting in relief, the exact counterpart of that from which the drawings were made; the same optical effect is produced as by the object itself, and the appearance of solidity and projection are perfectly imitated.

THE STEREOSCOPE.

This is the principle of the instrument referred to above, which is known as the stereoscope. It is simply a framework holding two photographic views of the same object, which have been taken from two different points of view, corresponding to the different positions of the two eyes.

Thus one of the pictures represents the object as it would in reality be seen by the right eye, and the other represents it as it would be seen by the left eye. When these two pictures are so placed in the stereoscope that each eye has presented to it its own appropriate view, the two images occupying the point of fixation are fused upon the retina, and produce an extremely deceptive resemblance to the projection and solidity of the real object.

By transposing two stereoscopic pictures a reverse effect is produced; the elevated parts appear depressed and the depressed parts appear to be elevated. Viewed in this way a bust would appear as a hollow mask.

But this combination of two different images into one, giving rise to the impression of solidity, is complete in effect only when the object is situated within a moderately short distance. For those which are comparatively remote, the convergence of the visual axes, and consequently the difference in the apparent configuration of the two images, is so little as to become inappreciable, and the optical impression of solidity disappears. At a distance of some miles even a large object like a mountain loses its projection and presents the form of a flattened mass against the horizon. It is on this account that pictorial representations of distant views can often be made extremely effective; the idea of successive remoteness in different parts of the landscape being conveyed by appropriate intersection of the outlines and by variations in tone, color and distinctness, like those due to the interposition of the atmosphere.

On the other hand, a picture of near objects, which aims to represent their solidity, can never deceive us in this respect, however elaborate may be the details of surface, shadow and color, since the flat surface of the picture presents the same image to both eyes, and it is consequently evident that the objects delineated have no real projection.

APPARENT POSITION OF OBJECTS.

The apparent position of an object is determined by the direction in which the luminous rays pass from it to the interior of the eye. The perception of the light itself necessarily marks the direction from which it has arrived, and therefore the apparent position of its source. The result is that a ray coming from below attracts attention to the inferior part of the field of vision, while one coming from above is referred to its point of origin in the upper part of the same field.

Thus, if two luminous points appear simultaneously in the field of vision, they present themselves in a certain position with regard to each other, above or below, to the right or to the left, according to the direction in which their light has reached the eye. This fact is fully demonstrated by the phenomena of angular reflection and refraction. If a candle be held behind the back in such a position as to be reflected in a mirror placed at the front, the light presents itself to the eye as if it were really in front, because it is from this direction that the luminous rays finally come.

If we observe the reflection of objects in a mirror held horizontally, or in a smooth sheet of water, the objects seem to be placed below the reflecting surface (although we know they are really above it), since the rays which make their impression upon the eye actually come from below. A stick or pebble seen obliquely at the bottom of a transparent pond appears nearer the surface than it really is, because the rays which reach the eye have been bent from their course in passing from the water into the atmosphere, and have consequently assumed a more oblique direction.

ACUTENESS OF VISION.

The acuteness of vision, so far as it is connected with the sensibility of the retina, depends upon the smallest distance from each other of two visual rays at which they can still be perceived as distinct points. If the luminous rays coming respectively from the top and bottom of an object are so closely approximated where they strike the retina that the two impressions are confounded, there can result no distinct impression or perception of its figure or dimensions.

On the other hand, if the rays are far enough apart, and the sensibility of the retina be such that the two impressions are perceived as separate from each other, the form of the object will be recognized, as well as its luminosity, notwithstanding the small size of the retinal image.

The figure of a man six feet high seen at a distance of ten yards forms at the cornea a visual angle of 11° 30′, and produces upon the retina an image which is less than one-fiftieth of an inch in length; and yet an abundance of details are distinctly perceptible in this space.

The extreme limit of approximation at which two points may still be distinguished from each other has been examined by the observation of fixed stars, and of parallel threads of the spider's web, or of fine metallic wires placed at known distances from each other. The general result of these examinations has shown that for the average of well-formed eyes the smallest visual angle at which two adjacent points or lines can be distinguished is from sixty to seventy-three seconds.

DURATION OF VISUAL SENSATION.

The *duration* of the sensation produced by a luminous impression upon the retina is always greater than that of the impression that produces it. However brief the luminous impression, the effect on the retina always lasts for about one-eighth of a second. Thus, supposing an object in motion, say a horse, be revealed on a dark night by a flash of lightning; the horse would be seen apparently for an eighth of a second, but it would not appear in motion; because, although the image remained on the retina for this time, it was really revealed for such an extremely short period (a flash of lightning being almost instantaneous) that no appreciable motion on the part of the object could have taken place in the period during which it was revealed to the retina of the observer.

And the same fact is proved in a reverse way. The spokes of a rapidly revolving wheel are not seen as distinct objects, because at every point of the field of vision over which the revolving spokes pass, a given impression has not faded before another comes to replace it. Thus every part of the interior of the wheel appears occupied.

REFLECTION FROM THE EYE.

It is quite evident that the more luminous a body, the more intense is the sensation it produces. Part of the light which enters the eyes is absorbed and produces certain changes in the retina, while the rest is reflected.

Every one is perfectly familiar with the fact that it is quite impossible to see the fundus, or back part of another person's eye by simply looking into it. The interior of the eye forms a perfectly black background to the pupil. The same remark applies to an ordinary photographer's camera, and may be illustrated by the difficulty we experience in seeing into a room from the street through a window, unless the room be lighted within.

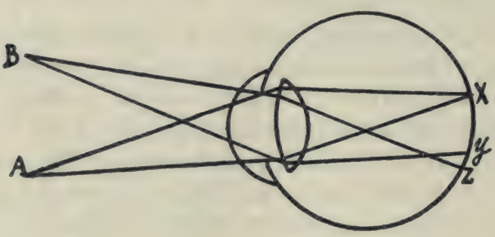
In the case of the eye this fact is partly due to the feebleness of the light reflected from the retina, most of it being absorbed by the choroid, as has been mentioned; but far more to the fact that every such ray is reflected straight back to its source, and cannot, therefore, be seen by the unaided eye without intercepting the incident light from the candle as well as the reflected rays from the retina. This difficulty has been surmounted by the ingenious device of Helmholtz, which is now so extensively used as the ophthalmoscope. It consists of a small, slightly concave mirror, by which light is reflected from a candle into the eye. The observer looks through a hole in the mirror and can thus explore the illuminated fundus, the entrance of the optic nerve and the retinal vessels being plainly visible.

The method by which a ray of light is able to stimulate the endings of the optic nerve in the retina in such a manner that a visual sensation is produced and perceived by the brain is not yet fully understood.

PERFECT AND IMPERFECT FOCUS UPON RETINA.

The apparatus of vision, as it has been described, consists of various parts, each of which has its appropriate share in producing the final result of visual perception. The eye, as regards its physical structure,is an optical instrument, as has already been stated, composed of transparent and refracting media, a perforated diaphragm, and a dark chamber lined with a blackened membrane, all of which act upon the luminous rays according to the same laws as the corresponding parts in a telescope or camera, and the accuracy of the adjustment of these structures is one of the first requisites for the exercise of sight. The eye, furthermore, is movable as a whole, and certain of its internal parts are also under the control of muscular tissues, the alternate contraction and dilatation of which contribute to determine its mode of action. It is, in addition, a double organ, and impressions may be derived from the simultaneous employment of both eyes which can not be acquired by the use of one alone.

Rays of light entering the eye from the front, in the line of direct vision, may be brought to an accurate focus at the situation



of the retina. But those which enter at a certain degree of obliquity, whether from above or below, from one side or the other, suffer a more rapid convergence, and are accordingly brought to a focus and again dispersed before reaching the retina.

Thus, rays diverging from the point *A* in the line of direct vision are concentrated at *X*, and form a distinct image upon the retina at that point.

But those proceeding from the point *B*, which is situated considerably to one side, under a similar degree of divergence, fall upon the cornea and crystalline lens in such a way that there is more difference in their angles of incidence, and consequently more difference in the degree of their refraction. They are therefore brought together too rapidly and are dispersed upon the retina over the space *Y Z*, forming an imperfect image.

Ophthalmoscopic examination of the retina shows that the images formed at the fundus of the eye from luminous objects in the line of direct vision present perfectly distinct outlines, while those at a certain distance from this point toward the lateral parts of the retina are comparatively ill-defined.

ESTIMATION OF SIZE.

Our estimate of the size of various objects is based partly on the visual angle under which they are seen, but much more on the estimate we form of their distance from us Thus, a lofty mountain, many miles away, may be seen under the same visual angle as a small hill near at hand, but we infer that the former is much the larger object because we know that it is much farther off than the hill. But it often happens that our estimate of distance is erroneous, and consequently our estimate of size will also often be faulty. Thus, persons seen walking on the top of a small hill against a clear twilight sky appear unusually large, because we over-estimate their distance; and for similar reasons most objects in a fog appear immensely magnified.

The same mental process gives rise to the idea of depth in the field of vision. The action of the sense of vision, in relation to external objects, is therefore quite different from that of the sense of touch. The objects of the latter sense are immediately present to it; and our own body, with which they come in contact. is the measure of their size. In the sense of vision, on the contrary, the images of objects realized upon the retina are mere fractions of the objects themselves, the extent of the retina always remaining the same. But the imagination, which analyzes the sensations of vision, invests the images of objects with varying dimensions, the relative size of the image in proportion to the whole field of vision remaining unaltered.

The *estimation of the direction* in which an object is seen depends on the part of the retina which receives the image, and on the distance of this part from the central point of the retina.

The *estimation of the form* of bodies by sight is the result partly of the mere sensation and partly of the association of ideas

RODS AND CONES OF RETINA.

The clearness with which an object is perceived, irrespective of accommodation, would appear to depend largely on the number of rods and cones which its retinal image covers. Hence, the nearer an object is brought to the eye (within moderate limits) the more clearly are all its details seen. Moreover, if we want to examine any object carefully, we always direct the eyes straight to it, so that its image shall fall on the yellow spot, where an image of a given area will cover a larger number of cones than anywhere else in the retina. The diameter of each cone in this part of the retina is about one twelve-thousandth of an inch, and consequently it has been found that the images of two points must be at least one twelve-thousandth of an inch apart on the yellow spot in order to be distinguished separately; if the images are nearer together, the points appear as one.

ERECT VISION WITH AN INVERTED IMAGE.

Since it is the direction of the visual rays, as well as the point of their impact upon the retina, which determines the apparent relative position of luminous objects, such objects appear erect even though their images upon the retina are inverted. The image formed upon the retina is not the form which is seen by the eye and recognized by the brain, but this retinal image is only a phenomenon visible to the inspection of another eye.

Every optometrist knows that the image that is formed upon the retina is in an inverted position, and this at once very naturally raises the question as to why we do not, therefore, see everything upside-down. This is a subject on which much has been said and written, and many ingenious explanations have, from time to time, been advanced, and it has become really quite a bugbear to optical students. The question briefly stated is this: How is it possible that we see objects erect when the images formed by them upon the retina are inverted?

The above figure represents the formation of an inverted image upon the retina of the eye. There has been much learned discussion as to the manner in which we receive the impression of an erect object from an inverted image.

THE LAW OF PROJECTION.

It should be remembered that, after all, it is not the eye that sees, but the brain, and it sees, not the image formed upon the retina, but what is called the projection outward of this image, just as the picture of the magic lantern slide, which is placed in the lantern upside-down, projects an erect image upon the screen. In other words, when the inverted image is formed upon the retina, we refer the sensation in the same direction as the rays that produce it; hence, in that part of the image that is formed on the upper part of the retina, we refer the sensation downward along the line from which its rays must have come; and in like manner that part of the image that is formed on the lower part of the retina is referred upward; hence the image rectifies itself.

To explain more minutely: The direction given to rays by their refraction is regulated by that of the central ray or axis of

the cone toward which the rays are bent. The image of any point of an object is, therefore, as a rule, always formed in a line identical with the axis of the cone of light, as in the line *B a*, or *A b*, so that the spot where the image of any point will be formed upon the retina may be determined by prolonging the central ray of the cone of light, or that ray which passes through the nodal point.

Thus, *A b* is the axis or central rays of the cone of light issuing from *A*; *B a* the central ray of the cone of light issuing from *B*. The image of *A* is formed at b, the image of *B* at *a*, in the inverted position; therefore, what in the object was above is in the image below, and *vice versa*. The right-hand part of the object is in the image to the left, the left-hand to the right.

INSPECTION OF RETINAL IMAGE.

If an opening could be made in an eye at its upper surface, so that the retina could be seen through the vitreous humor, this reversed image of any bright object, such as the windows of a room, would be perceived at the bottom of the eye; or, still better, if the eye of any albino animal, such as a white rabbit, in which the coats, from the absence of pigment, are transparent, is dissected clean and held with the cornea toward the window, a very distinct image of the window, completely inverted, will be seen depicted on the posterior translucent wall of the eye.

An image formed at any point on the retina is referred to a point outside the eye, lying on a straight line drawn from the point on the retina outward through the center of the pupil. Thus an image on the left side of the retina is referred by the mind to an object on the right side, and *vice versa*. Thus all images on the retina are mentally, as it were, projected in front of the eye, and consequently all objects are seen erect, even though the image on the retina is reversed.

INTERPRETATION BY THE BRAIN.

Much needless difficulty and confusion have been raised on this subject for want of remembering that when we are said to see an object the mind is merely conscious of the picture on the retina, and when it refers it to the external object, or projects it outside of the eye, it necessarily reverses the picture and sees the object erect, while at the same time the retinal image is inverted. This is further corroborated by the sense of touch; thus, an object whose picture falls on the left half of the retina is reached by the right hand, and hence is said to lie to the right; or, again, an object whose image is formed on the upper part of the retina is readily touched by the feet, and is therefore said to be in the lower part of the field of vision.

Hence it is, also, that no discordance arises between the sensations of inverted vision and those of touch, which perceives everything in its erect position, for the images of all objects, even of our own hands and feet, are equally inverted on the retina, and therefore maintain the same relative position. The position in which we see objects we call the erect position. A mere lateral inversion of our body in a mirror, where the right hand occupies the left of the image, is indeed, scarcely remarked; and there is but little discordance between the sensations acquired by touch in regulating our movements by the image in the mirror and those of sight, as, for example, in tying a bow in a cravat. The perception of the erect position of objects appears, therefore, to be the result of an act of the mind.

FIELD OF VISION.

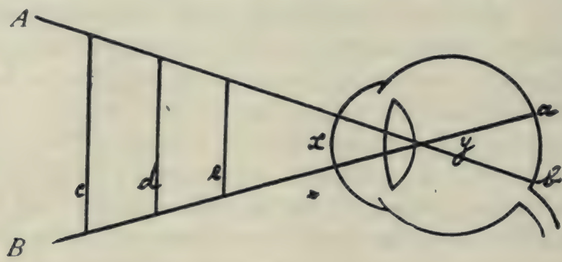
The actual size of the field of vision depends upon the extent of the retina, for only so many images can be seen at any one time as can occupy the retina at the same time; and thus considered, the retina, the images on which are perceived by the mind, is itself the field of vision. But to the mind of the individual the size of the field of vision has no determinate limits; sometimes it appears very small, at other times very large. The mental field of vision is very small when the sphere of the action of the mind is limited to impediments near the eye; on the contrary, it is very extensive when the projection of the images on the retina, toward the exterior, by the influence of the mind is not impeded. It is very small when we look into a hollow body of small capacity held before the eyes; it is large when we look out upon a landscape, through a small opening; more extensive when we view a landscape through a window, and most so when our view is not confined by any near object.

In all these cases the idea which we receive of the size of the field of vision is very different, although its absolute size is the same in all, because it is dependent upon the extent of the retina. Hence it follows that the mind is constantly co-operating in the acts of vision, so that at last it becomes difficult to say what belongs to mere sensation and what to the influence of the mind. By a mental operation of this kind we obtain a correct idea of the size of individual objects, as well as of the extent of the field of vision. This is illustrated in the figure on page 72.

THE OPTICAL ANGLE.

The angle x, included between the decussating central rays of the two cones of light issuing from different points of an object, is called the optical angle. This angle becomes larger the greater the distance between the points A and B, and since the angles x and y are equal, the distance between the points a and b, in the image on the retina, increases as the angle becomes larger.

Objects at different distances from the eye, but having the same optical angle x (for example, the objects c, d and e), must also throw images of equal size upon the retina; and if they occupy the same angle of the field of vision their images must occupy the same spot on the retina. Nevertheless, these images appear to the mind to be of very unequal size when the idea of distance and proximity comes into play, for from the image *a b* the mind forms the conception of a visual space extending to *e*,



d or *c*, and of an object of the size which that represented by the image on the retina appears to have when viewed close to the eye or under the most usual circumstances.

ESTIMATION OF MOVEMENT.

We judge of the motion of an object partly from the motion of its image over the surface of the retina and partly from the motion of our eyes necessary to follow it. If the image upon the retina moves while our eyes and our body are at rest, we conclude that the object is changing its relative position with regard to ourselves. If, on the other hand, the image does not move with regard to the retina, but remains fixed upon the same spot of that membrane, while our eyes follow the moving body, we judge of its motion by the sensations of the muscles called into action to move the eye. If the image moves over the surface of the retina while the muscles of the eye are acting at the same time in a direction corresponding to this motion, as in reading, we infer that the object is stationary, and we know that we are merely altering the relation of our eyes to the object. Sometimes the object appears to move when object and eyes are both fixed, as in vertigo.

COLOR SENSATIONS.

If a ray of sunlight be allowed to pass through a prism it is decomposed by the prism into rays of different colors, which are called the colors of the spectrum. They are red, orange, yellow, green, blue, indigo and violet. The red rays are the least turned out of their course by the passage through the prism, and the violet rays the most, while the other colors occupy in their respective order places between these two extremes. The difference in the color of the rays depends upon the number of vibrations producing each, the red rays being the least rapid, and the violet the most. These colored rays, which are perceived by the brain as such, must stimulate the retina in some special manner in order that colored vision may result.

The ocular spectra, which follow the impression of colored objects upon the retina, are also always colored; but their color is not the same as the object or of the image produced directly by the object, but the opposite, or complemental, color. The spectrum of a red object is, therefore, green; that of a green object, red; that of a violet, yellow; that of a yellow, violet, and so on. The reason of this is obvious: the part of the retina which receives a certain color, say a red image, is wearied by that particular color, but remains sensitive to the other rays which, with red, make up white light; and therefore these by themselves, reflected from a white object, produce a green hue. If, on the other hand, the object first looked at be green the retina, being tired of green rays, receives a red image when the eye is turned to a white object. And so with other colors; the retina, while fatigued by yellow rays, will suppose an object to be violet, and *vice versa*. Of course, the size and shape of the spectrum always correspond with the size and shape of the original object looked at.

Color-blindness is by no means uncommon visual defect. One of the commonest forms is the inability to distinguish between red and green; the explanation of this is that the elements of the retina which receive the impression of red are absent or very imperfectly developed. Color-blindness is a most interesting subject, and we hope later on to give some attention to it, but just now other subjects, more practical and important, are pressing for attention.

The red-blind see light red and dark green alike; to the green-blind light green and dark red are identical. In both the red- and green-blind yellow and blue are normal. Color-blindness is detected by the Holmgren test, in which the patient is required to match a test skein from a pile of worsteds of various colors, shades and tints.

SINGLE VISION WITH TWO EYES.

Although the sense of sight is exercised by two organs, yet the impression of an object conveyed to the mind is single. Various theories have been advanced to account for this phenomenon. By some authorities it has been supposed that we do not really employ both eyes simultaneously in vision, but see with only one at a time. This especial employment of one eye only in vision certainly occurs in persons whose eyes are of very unequal refraction, but in the majority of individuals both eyes are simultaneously in action in the perception of the same object. This is proven by the double images seen under certain conditions.

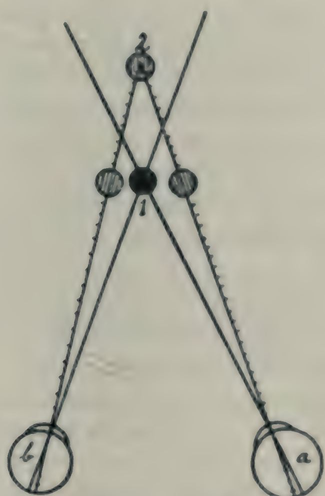
If two fingers be held before the eyes, one in front of the other, and vision be directed to the more distant so that it is seen singly, the nearer one will appear double; while if the nearer one be regarded, the distant one will be seen double; and in each case one of the double images will be found to belong to one eye, the other image to the other eye.

BINOCULAR FIXATION.

As has already been stated, distinct vision is possible for an eye only for objects situated in the line of direct vision. Now, since the eyes are placed in their orbits at a certain distance from each other, when they are both directed at the same object their lines of direct vision converge and cross each other at a single point. At this point of intersection of the two lines of direct vision an object may be seen distinctly by both eyes at the same time. But at every other point it must appear indistinct to one of them; there is, therefore, only a certain distance directly in front at which an object can be distinctly seen simultaneously by both eyes, namely, at that point where the two lines of direct vision intersect each other. This point is called the point of fixation for the two eyes. In fixing any object for binocular vision, the accommodation in each eye is at the same time adjusted for the required distance, and thus the entire accuracy of both organs is concentrated upon a single point.

Since it is the position of the two eyes in their respective orbits which determines the point of fixation, the observer can form a tolerably accurate judgment as to whether another person within a moderate distance can be looking at him, or at some other object farther removed in the same direction.

From the preceding facts it is evident that only one point can be found in the line of direct vision for both eyes at the same time. When an object occupies this situation it is distinctly perceived by both eyes in the center of the field of vision. Thus its two visual images exactly cover each other in their apparent position, and so form but one. Consequently, the object appears single, though seen by both eyes. But if placed either within or beyond the point of fixation, the object appears indistinct and at the same time double.



Single and double vision at different distances. *a*, right eye. *b*, left eye. *1*, object at the point of fixation, seen single. *2*, object beyond the point of fixation, seen double.

When the eyes are so directed that the nearer object (*1*) occupies the point of fixation, the farther object (*2*) will also be seen, because it is still included in the visual field; but it will be seen indistinctly, because the accommodation of the eye is no longer adjusted to its distance, and because it is not in the line of direct vision. But for the right eye (*a*) it will be placed to the right of this line, and for the left eye (*b*) to the left of it Its two images do not correspond with each other in situation, and the object accordingly appears double.

If the eyes, on the other hand, be directed to the more distant object, the nearer one is no longer in the point of fixation. For the right eye, its image will appear to the left of the line of direct vision, and for the left eye, to the right of this line, and it therefore appears double and indistinct.

Thus, in the ordinary use of binocular vision, every object but one appears double and at the same time imperfectly delineated. This circumstance is so little noticed that it is never a source of confusion for the sight, but even requires a special experiment to demonstrate its existence. The reason for its passing unobserved is two-fold: first, the attention is naturally concentrated upon the object which is placed for the moment at the point of fixation. When this point is shifted the new object upon which it falls also appears single, and thus the idea of a double image, even if indistinctly suggested at any time, is at once dispelled by the movements of the eyes in that direction.

In the second place, an object which is really placed in any degree toward the right-hand or the left will form an indistinct double image, since it occupies a different apparent position for the two eyes. But the obliquity of its rays, and consequently the indistinctness of its image, will be greater for the right eye than for the left, and *vice versa;* and the notice of the observer, if drawn to it at all, is occupied with the more distinct of the two images to the exclusion of the other.

Double vision may also be produced at any time by pressure with the finger at the external angle of one of the eyes, so as to alter its position in the orbit, the other eye remaining untouched. But in this case it is the whole field of vision that is displaced, and all objects are doubled indiscriminately; their images being separated to the same degree and in the same direction, whatever may be their distance from the eye. It is this form of double vision which is produced in vertigo or intoxication, by irregular action of the muscles of the eyeball.

RETINAL SENSIBILITY.

The sensibility of the retina is diminished by continued visual impressons, and this fact becomes apparent by the following test. If one eye be covered by a dark glass and the other be used exclusively for an hour or two in reading or writing, at the end of that time the difference in the retinal sensibility of the two eyes will be marked. A single faintly luminous object in a dark room may then be almost imperceptible to the eye that has been exhausted by the hour's use, while it will appear quite brilliant to the other eye. If the application of the eye has not been carried beyond the bounds of moderation, this difference is transitory. By reversing the conditions—that is, by covering the eye previously in use and reading or writing by the other—that which before was the most sensitive to light becomes less so and that which was previously fatigued recovers its sensibility.

NEGATIVE IMAGES.

The alternate diminution and recovery of the retinal sensibility by excitement and repose is directly connected with the phenomenon of *negative images.* If the eye be steadily fixed for a short time upon a white spot in the center of a black ground and then suddenly directed toward a blank wall of a uniform white or light gray color, a dark spot will appear at its center of the same apparent size and figure as the white one previously observed. This is the "negative image" of the retinal impression. That part of the retina which was first impressed by the rays from the white spot becomes less sensitive to light, and consequently another white surface, looked at immediately afterward, appears darker than usual. On the other hand, those parts which were exposed only to the dark ground—that is, to the comparative absence of light—are more sensitive than before, and the surface of the white wall outside the central dark spot appears brighter than usual.

In further illustrating this phenomenon of negative images let a black ruler about an inch wide be laid upon a sheet of white paper and looked at steadily for thirty or forty seconds. If the ruler be now removed by a sudden motion, the eye remaining fixed, its image will appear as a bright band upon the paper, fading gradually as the sensibility of the retina becomes equalized in its different parts.

If the figure which is thus examined be a colored one, its negative image, subsequently produced, will present a complementary hue to that of the original object. A strip of red paper placed upon the white sheet and then suddenly removed leaves a negative image which is bluish-green, and a green strip of paper leaves an image which is decidedly reddish. This shows that the sensibility of the retina may be increased or diminished separately for the different colored rays of the luminous beam. While looking at the red object, the retina partly loses its sensibility for the red rays while increasing it for those at the opposite end of the spectrum, and *vice versa;* so that on looking subsequently at a white object the negative image exhibits a tint corresponding to the rays for which the retina has remained most sensitive.

That this is the mechanism of the production of complementary colors in negative images becomes evident by another experiment. If the black ruler be laid upon a blue surface, the band which remains in its place after taking it away is of a more intense blue than the rest. If a red surface be used for the same purpose, the negative image of the ruler presents a remarkably pure red color, while the remainder of the surface appears of a dull brown.

WHEN INDIRECT VISION IS OF VALUE.

The variable sensibility of the retina, according to its exposure, affords an explanation of the well-known fact that under certain conditions an object may be most easily perceived by indirect vision. It often happens that in searching for a star of very small magnitude and feeble light, it may be momentarily perceived by looking not directly at it but at a point in its immediate vicinity at a small angular distance from its real position. The star is not seen distinctly under these circumstances, because it is out of the line of direct vision; but its light falls upon a part of the retina near the yellow spot, the sensibility of which is more acute than usual, owing to its continued exposure only to the dark sky; while the yellow spot itself, which has been receiving in succession the images of particular stars, is comparatively deficient in impressibility to light. When the visual axis is turned directly upon the fainter star for the purpose of getting a distinct image, its light disappears, and thus it can only be seen as an evanescent object by indirect vision.

If the eye be fixed immovably for too long a time upon the same luminous object, the local diminution of retinal sensibility may amount to fatigue; and a persistence in its continuous application may produce permanent injury to the visual organ.

After steadily examining a single object for even a short time it becomes difficult to resist the tendency to turn the sight in another direction by the automatic movement of the muscles of the eyeball. Naturally, the eye never rests for more than a few seconds upon any one point in the field of view, but is directed in succession at different objects, fixing each one in turn at the point of distinct vision and immediately passing to another more or less remote. Thus fatigue of the retina is avoided, since those parts which at one instant have a stronger illumination, at the next instant receive the impression of a shadow; and no portion of the membrane is exposed sufficiently long to any single object to become insensible to its grade of light or color.

There is, also, reason to believe that the eye requires for its safety a periodical suspension of all visual impressions, such as is obtainable only in *sleep*. It is not essentially different in this respect from other parts of the nervous apparatus of animal life; but the delicacy of its sensibility, which is requisite for the due performance of its function, and the complication of its structure, which includes so many parts adjusted to each other with mathematical accuracy, indicate that it is one of the organs most liable to derangement if deprived of its natural interval of restoration and repose.

We have now gone over the anatomy of the eye and the physiology of vision, covering the ground pretty carefully. Much of what has been said above may have seemed somewhat tedious and uninteresting, but it is important knowledge for the optometrist to possess as a foundation for the more practical matter which is to follow.

CHAPTER IV.

PRINCIPLES OF OPTICS.

Before taking up the consideration of the various defects of the eye and their correction by glasses, we must first give some attention to the study of the fundamental principles of the science of optics.

Optics is that branch of science which treats of the nature and properties of light and the phenomena of vision. There are two sub-divisions of Optics, as follows:

Catoptrics is that branch of Optics which treats of the laws that pertain to the reflection of light from polished surfaces.

Dioptrics is that branch of Optics which treats of the laws pertaining to refraction of light as it passes through media of varying densities.

Light may be defined as a form of radiant energy which acts upon the sentient elements of the retina in such a way as to excite in the mind the impression of vision. A substance which emits light of its own generation is said to be luminous.

Light is emitted from every point of a luminous body in successive waves, like the circles which form on a pond of still water when a stone is thrown into it. The number of waves per second, and consequently the wave lengths, vary with the nature of the luminous body.

Ether is the extremely tenuous medium which exists in all space, penetrating everywhere. Radiant energy causes it to vibrate, imparting to it a wave-like motion, and to certain of these waves the eye is sensitive. This is the wave, or undulation, theory of light, about which so much has been written and said of late years.

Some such medium must exist capable of transmitting light in order to account for the action of light, a vibratory motion of the particles of this ether taking place in the direction in which the waves move.

Representing light waves emitted in all directions from a candle flame. A line from a luminous point perpendicular to a wave front represents a *ray* of light. It is the smallest subdivision of light traveling in a straight line.

A *Beam* of light is a collection or series of parallel rays.

A *Pencil* of light is a bundle of convergent or divergent rays.

Parallel rays are those which constantly maintain the same distance between each other.

Convergent rays are those which tend to a common point.

Divergent rays are those which proceed from a radiant point

and constantly separate and get farther apart.

Light always moves in straight lines and travels at the rate of 186,000 miles per second. It cannot bend around corners, as sound does.

A *transparent* body is one that transmits light freely so that objects can be distinctly seen through it, as glass.

A *translucent* body is one that obstructs the light somewhat, transmitting a softened or diffused light, through which objects cannot be seen, as porcelain.

An *opaque* body is one through which light cannot pass.

A *medium* is any transparent substance that permits the passage of light.

Rays of light given off by a luminous body are always divergent; in fact, strictly speaking, all light exists in the form of diverging rays. Nature knows no convergent rays, nor any that are absolutely parallel.

It can be understood that the amount of divergence of the rays received on a given surface must be proportionate to the distance of that surface from the point whence the rays come.

In this figure the two perpendicular lines represent two surfaces of equal dimensions. A single look shows that the divergence of the rays proceeding from a luminous point L to the surface a b is greater than the divergence of the rays which

are received on the surface c d. If this diagram be greatly enlarged, the divergence of the lines striking the surface c d will be so slight that, on isolating any small portion of them, they will appear almost parallel. Hence it can be easily understood that any two rays of light proceeding from a luminous point in the sun, distant more than ninety-four millions of miles, and entering the opening of the pupil of the human eye, which is less than a quarter of an inch in diameter, must form with one another so small an angle as not to be appreciable, and such rays (that is, rays proceeding from infinite distance) are, therefore, always assumed to be parallel. In optics, then, we have these two facts laid down as general principles: First, that all rays of light proceeding from a distant source are said to be parallel; and, second, that all rays proceeding from a near source are divergent. Therefore, in dealing with rays that enter the eye it will be sufficiently accurate to consider them to be parallel if they proceed from a distance of twenty feet or more.

Rays of light are convergent only when made so by artificial means, as by reflection from a concave mirror, or refraction through a convex lens.

Every object we can see owes its visibility to rays of light proceeding from it to the retina. The bodies which emit rays of light, as the sun or a candle flame, are termed *luminous*.

Those which only reflect rays, as the moon, a clock-face or a mirror, are *illuminated*.

Luminous bodies are supposed to be composed of an indefinite number of luminous points giving off rays in all directions.

A single ray of light cannot be obtained, but a number together—that is, a beam or a pencil— may be easily demonstrated. Completely darken a room facing the sun, bore a small hole in the shutter, and a vivid, perfectly straight strip of light will be seen traversing the darkness, if the air of the room contains particles of solid matter, like dust or tobacco smoke.

The path pursued by the rays of light, whether from luminous or illuminated bodies, as long as they pass only through the atmosphere, is in straight lines and never in curves; but when they pass through other bodies or substances they may be diverted from their original course, always retaining, however, their straightness.

A ray of light moving through a homogeneous medium, such as the surrounding atmosphere, continues in a straight line forever, but meeting a solid body it may be either transmitted, refracted, reflected or absorbed, according to the nature of the obstructing body. If transparent with plane surfaces, it is transmitted, but not refracted. If transparent with curved surfaces, it is both transmitted and refracted. If opaque with polished surfaces, the light will be reflected. If opaque with dull, roughened surface, like a piece of black cloth, the light will be absorbed.

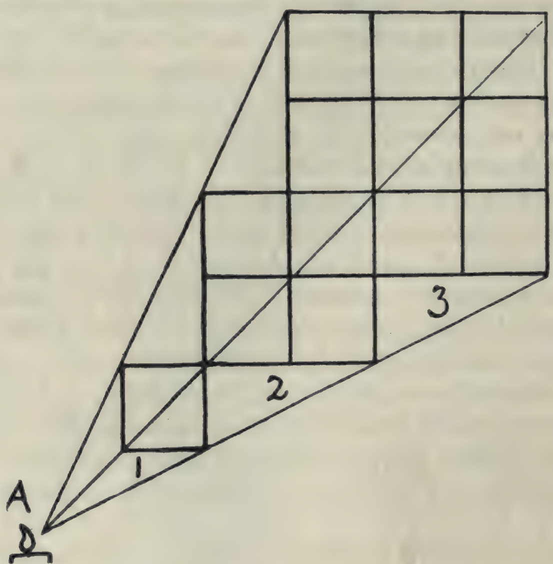
Absorption of certain of the light rays has the effect of giving an object color, as those returned to the eye produces the color effect. Objects that absorb none of the light rays but return all to the eye have the appearance of white; those that absorb all the rays and return none to the eye, appear black.

An object would be invisible if no light was reflected from it to the eye. Under good illumination light is reflected from all objects. When the reflection is slight, with no one color predominating, the object appears gray or black.

Light of a certain color may be freely reflected, while other colors are absorbed. The color which is predominantly reflected determines the color of the object.

It is a curious fact that no substance is perfectly transparent; all absorb or quench at least a portion of the rays, while others are reflected or scattered. If an object should be perfectly transparent it would not be visible, because all the rays would pass directly through it, and there would be no scattered rays to pass into the eye. Even the refractive media of the eye are not perfectly transparent. Neither are there objects perfectly opaque; the densest of metals, as gold, when beaten very thin, transmits a greenish light.

Opaque bodies placed before a source of light cast shadows on the background. In consequence of the straight lines in which light always moves, the form of the shadow will correspond to the outlines of the object, but its size will vary according to the distance of the object from the source of light, and of the screen from the object. That the edges of a shadow may be sharply defined, the light must proceed from a point; if, on the contrary, it comes from a luminous surface, the borders of the perfect shadow are surrounded by an imperfect shadow. This can be readily shown by a lamp having a flat wick, so as to make a broad, thin flame.



If the broad surface of the flame be turned toward a screen of white paper held two or three feet distant and a small body, like a knife-blade, be interposed, the real shadow will be seen surrounded by an imperfect one; while if the lamp be partly turned so that the edge of the flame be toward the screen and the knife-blade be again interposed, the shadow produced by it will be clear-cut and its edges perfectly defined.

The intensity of illumination produced by rays of light diverging from a luminous point diminishes in proportion to the square of the distance. A screen one foot square, distant one foot from a lighted candle, receives a certain number of rays and is illuminated accordingly. A screen two feet square, at two feet distance, receives the same number of rays, but they are spread over four times the surface; consequently each point on the second screen receives only one-fourth as many rays as a similar point on the first. So a screen three feet square, at a distance of three feet, receives the same number of rays as the smaller one at one foot, but they are spread out so as to cover nine square feet; hence the intensity of the illumination is but one-ninth of the first instance. This is well illustrated in the figure on page 84.

A represents the flame of a candle; *1*, *2* and *3* represent screens of one, two and three feet square, placed at corresponding distances from the flame. Each screen receives the same number of rays; but while at *1* they cover only one square foot, at *2* they are spread over four square feet, and at *3* nine square feet.

VELOCITY OF LIGHT.

It requires time for light to travel through space, although the rapidity with which it moves is so great that for distances which we are able to measure on the earth its passage seems almost instantaneous. According to the calculations of astronomers, light moves at the rate of about 186,000 miles in a second; hence it can be figured out that it requires a little more than eight minutes for the light of the sun to reach the earth.

REFLECTION OF LIGHT.

A ray of light meeting an opaque body may be either absorbed or reflected. If a piece of dark cloth be held at an angle of forty-five degrees to the beam of light admitted by a minute hole in the shutter into a darkened room, the light will be absorbed or disappear in the cloth. But if a mirror be placed in the same position, the light will be reflected and the beam will pass onward at right angles to its original course. Reflection of light varies in degree according to the quality of the surface upon which the light falls; rough, dark-colored surfaces reflect light very imperfectly, while light-colored and polished surfaces reflect very perfectly, even when light falls upon the surface of a transparent substance, while most of the rays are transmitted, yet some of them are reflected, and it is by this reflection the surfaces are made visible. If it were possible for all the rays of light to be transmitted or absorbed, a substance having such properties would be invisible.

The difference between a transparent and an opaque body lies in the structural peculiarity of the substance. A common illustration of this difference is afforded by ice or glass, both of which are transparent in their natural state, but become opaque when in a crushed or pulverized condition, the opacity in the latter case being due to the inter-mixture of air between the particles of the denser material.

The rays approaching and striking the surface of a body are called *incident rays;* those that are sent back into the medium whence they came are called *reflected rays.*

REFLECTION FROM PLANE SURFACES.

When light falls perpendicularly on any plane polished surface, as a mirror, it is thrown back and exactly retraces its first course. If a ray strikes the surface obliquely, as in the above instance, it is reflected obliquely. If, now, a ruler be placed perpendicular to the surface of the mirror at the point where the beam impinges, it will divide the angle made by the beam into two equal parts, as shown in the figure on opposite page.

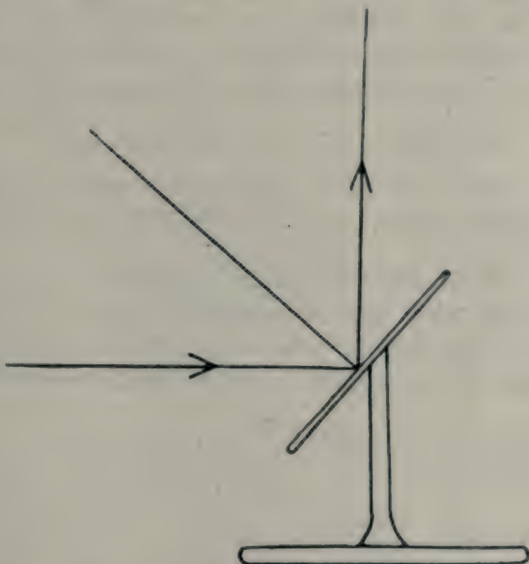
If the mirror be more inclined, with the ruler still remaining perpendicular to its surface, the angles will be larger, but still equal. If the inclination of the mirror be diminished, the angles will be small, but still equal; so that we find that the angle on one side of the ruler is always equal to the angle on the other side; or, in other words, the impinging ray and the reflected ray each forms a similar angle with a line perpendicular to the surface at the point of incidence; hence, the law which applies to the reflection of light is expressed by saying that "the angle of reflection is equal to the angle of incidence."

LAWS OF REFLECTION.

1. The angle of reflection is equal to the angle of incidence.
2. The incident and reflected rays are in the same medium.

In regard to the variation with which different bright-polished bodies reflect light, while black and dark-colored bodies absorb it, it may be said that if all the light would be absorbed by any object the object would be invisible, because there would be no rays left to enter the eye.

In the case of the mirror just mentioned, it is a flat surface reflecting light; but no surface is absolutely flat or plane; the denser metals can be made to approach the nearest to this condition, for which reason reflection from their smoothest surfaces is nearly perfect. When the smooth surfaces of objects, like polished wood or marble, are examined with the microscope, they are found to consist of an infinite number of small planes, inclined to each other at all possible angles. These planes scatter the light in every direction, and produce what is called diffuse light.



Illustrating the Law of Reflection.

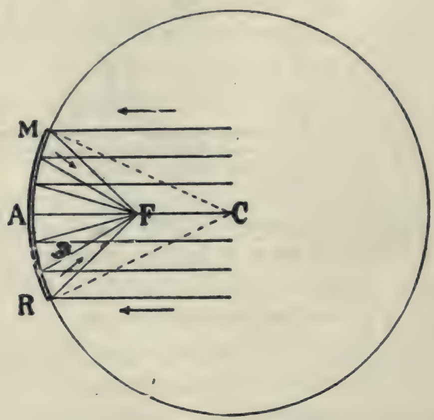
If a sunbeam pass through a perforation in the shutter of a dark room and impinge upon a highly polished metal surface, it is almost entirely reflected and strikes the wall, making a bright spot the same size as the beam, while the room remains dark. If a sheet of white paper be substituted for the polished surface, there will be no reflection of the beam as before, but instead there will be a faint general illumination all over the room. It is these irregularly-reflected or scattered rays that make non-luminous objects visible when they are illuminated.

In a plane mirror the reflected image appears as far behind its surface as the object is in front of it. The image is a perfect representation of the object in form and size and color, but it is laterally transposed, so that the left of the object becomes the right of the image, and the right of the object appears as the left of the image. When we stand before a mirror, the left half of the face appears as the right in the image, and the right half as the left in the image. Such an image is called virtual, in contradistinction to a real image. The reflected image of a printed page shows the letters arranged backward, and from right to left; they appear just as the compositor arranges his type. If this image be received and reflected by another mirror, the letters of the page are again seen in their accustomed position for reading. When the type is arranged for the printing press, a mirror enables us to read them the same as if their impressions were on paper.

REFLECTIONS FROM CURVED SURFACES.

A reflective surface may be curved, either convex or concave, and its centre of curvature would be the center of the sphere of which it forms a part.

The law that the angle of reflection equals the angle of incidence holds good when applied to regularly curved surfaces, for a curved surface may be regarded as a number of infinitely small planes inclined one to another. Each plane, or, rather, each



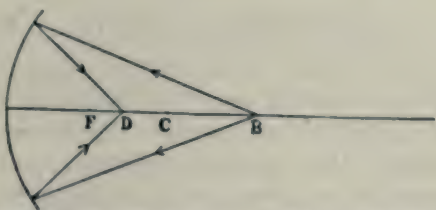
Showing a concave mirror as a section of a sphere, and its action in reflecting parallel rays.

point of the curved surface, would reflect a ray of light according to the law that has been stated.

Parallel rays striking upon a concave surface are reflected from it convergently and brought to a focus in front of it, at the principal focus of the mirror, which is just one-half the radius.

The diagram on page 88 represents a sphere, the center of which is *A C*. Any straight line drawn from *C* to the circumference will be a radius of the sphere and will be perpendicular to the circumference at the point of incidence.

If we consider the angle of incidence for each, it will be seen that parallel rays falling upon three planes inclined to one another, as *M*, *A* and *R*, would be reflected to a point situated as at *F*, and what is true of the three planes is approximately true of the infinity of plane surfaces contained in the curved surface. Parallel rays falling upon a concave mirror are reflected to a point situated upon the axis.



Reflection of divergent rays by a concave mirror.—Conjugate foci.

M R is a concave mirror, and as it is a section of the sphere, its center of curvature will be at *C*, which is the geometric center of the sphere. *M C* and *R C* will represent radii of the sphere.

If the rays that strike a concave surface are already divergent, they would be reflected to a point beyond the principal focus of the mirror. It is obvious, on a little thought, that the closer any luminous point approaches the mirror (and consequently the more diverging the rays that proceed from it) the farther its focal point will recede. And if the luminous point were to be situated at this focal point, the rays would be reflected back to the position of the first luminous point. These two points are called *conjugate foci*, and have a constant relationship, so that if the principal focal length is known, and the distance of one focus is given, the other can be determined by a mathematical formula.

The above diagram shows that rays of light proceeding from a point as *B*, which is situated upon the principal axis beyond the center of curvature *C*, will be brought to a focus at *D*. And, conversely, if the light was situated at *D*, the rays striking the same mirror would be brought to a focus at *B*. These two points *B* and *D* are thus seen to bear a definite relation to each other, light from either one is always reflected to the other, and hence they are known as *conjugate foci,* and their positions are reversible.

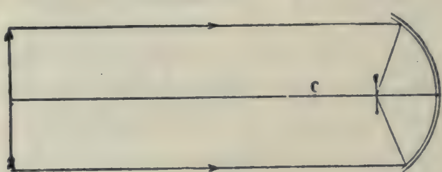
The distance from the vertex of the mirror to the principal focus is the focal length of the mirror. If a light were placed at the focal distance of the mirror, the rays would be reflected from the mirror, parallel. But if the light be placed at the center of curvature, it will be reflected from all points upon the surface of the mirror back to its source, because the path of each ray will be a radius of the mirror, and, as stated before, is always perpendicular to the small plane at the point of incidence.

IMAGES FORMED BY CONCAVE MIRRORS.

The image formed by a concave mirror may be real or virtual, inverted or erect, smaller or magnified, depending upon the location of the object whether nearer or farther than the principal focus. This is in contrast to a plane mirror, which produces images at all times and at all distances.

Parallel rays striking a concave mirror are brought to a focus at the principal focal distance, where they form a real, inverted, smaller image, as illustrated in the diagram below.

The arrow *A B* in the diagram on opposite page is situated closer to the mirror than its principal focus. Rays from the



arrow parallel to the principal axis impinge upon the mirror and are reflected and made to meet at the principal focus *F*. A ray from *A* strikes the mirror at *H* and is reflected to *F*. A secondary axis from *A* to *G* is reflected back over the same course to *C*. These reflected rays, *G C* and *H F*, are divergent, and therefore can never meet. They have no real focus, but only a virtual one, which is found by continuing these rays by imaginary lines back of the mirror, where they will meet to form the virtual focus and the imaginary image, which is erect and magnified.

The action of a concave mirror may be summarized as follows:

When object is placed at principal focal distance of mirror, no image is formed, because the rays are parallel.

Showing formation of a virtual magnified image by a concave mirror.

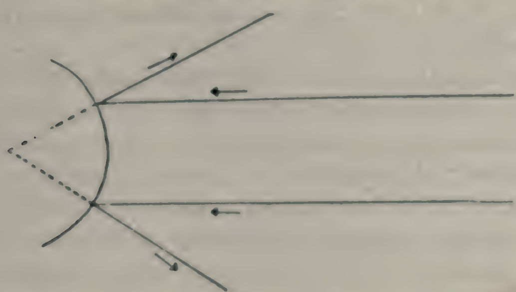
When object is placed closer than the focal distance, an *erect* and *magnified* image is produced.

When object is beyond the focal distance, the image is *inverted* and *magnified*, diminishing in size as object is removed.

When a concave mirror is tilted, an object placed inside its focal distance will appear to move *with* it, if beyond focal distance, *against* it.

REFLECTION FROM CONVEX SURFACES.

With convex mirrors all the above facts are reversed. In following the rays, we have hitherto seen them converge to a real or positive focus; but in the case of a convex spherical surface,



parallel rays are rendered divergent, and therefore no positive or real focus is formed. But if the divergent rays are continued by imaginary lines to the far side of the mirror, they will be found to meet in a point corresponding to the principal focus of a concave mirror of the same curvature. As the focus is imaginary and on the opposite side of the mirror from the actual rays, it is termed *negative;* and as the divergent rays have the same optical properties as if they came from the negative point, the focus is termed *virtual.*

IMAGES FORMED BY CONVEX MIRRORS.

The image formed by reflection from a convex mirror is always *virtual, erect* and *smaller* than the object. The closer the object, the larger the image; the farther the object, the smaller the image.

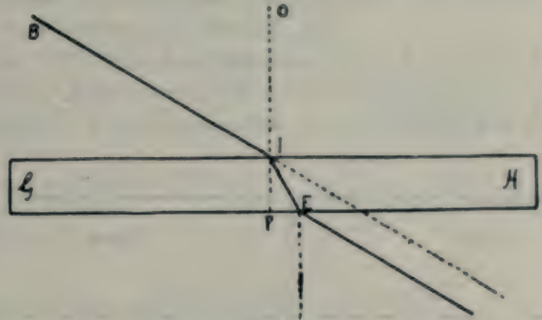
DIFFUSED LIGHT.

The surface of a mirror is so even as to reflected light in definite directions, but every kind of a body reflects light in some way. When the surface is uneven or irregular, the incident rays are not regularly reflected, but are reflected in all directions promiscuously or scattered. This is what is known as *diffusion* of light, by means of which most objects that we see are rendered visible. Such objects are said to be illuminated, and are visible from any direction because they receive and reflect light from all directions.

REFRACTION OF LIGHT.

When a ray of light passes from one homogeneous medium to another homogeneous medium of different density from that of the first, it is bent at the surface of separation, and proceeds in the second medium in a straight line, but in a changed direction. This is true of all rays that do not fall perpendicularly to the surface of separation.

Refraction of light may be defined as the deviation which takes place in the direction of its rays as they pass from one medium to another of different density. The word refraction is taken from the Latin language, and means, literally, to bend or to break. Those rays which are perpendicular to the surface are not bent, but proceed through the second medium in an unchanged direction. Rays which fall obliquely on the surface form an angle with the perpendicular at the point of incidence, called the *angle of incidence.* At the surfaces of the second medium the rays take another direction, and form a different angle with the perpendicular, and this is called the *angle of refraction,* and it usually is not equal to the angle of incidence. These two angles, that is, the angle of incidence and the angle of refraction, always have definite and fixed relations to each other, and it is the enunciation of these relations that constitutes the laws of refraction.



When a ray of light passes obliquely from a rarer to a denser medium, it is generally bent *toward* the perpendicular; on the contrary, when it passes from a denser to a rarer medium, it is bent *from* the perpendicular. This is shown in the above figure

G H represents a strip of plate glass with parallel surfaces and *O P* the perpendicular. A ray of light falling in the direction *O P* passes through the glass unrefracted. *B I* is an incident ray passing through the air (which is a very rare medium) and falling on the surface of the glass (which is a very dense medium) at the point *I*, where it is bent toward the perpendicular and proceeds in a straight line to *E*. Here it again meets the air (the first medium), and is bent from the perpendicular and continues in a line parallel to its first course.

The more obliquely the light falls on the refracting surface, the greater is the amount of refraction which its rays undergo; hence the degree of refraction varies with the angle of incidence, but the relation that one bears to the other remains unchanged. All the rays of light impinging on a refracting surface do not enter it; a part are reflected or thrown back into the first medium. The larger the angle of incidence, the greater will be the number of reflected rays.

THE LAWS OF REFRACTION.

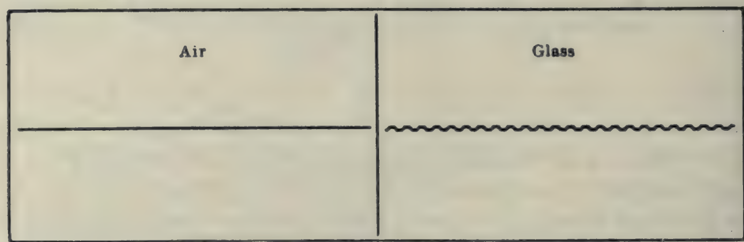
The laws of refraction may be summarized, then, as follows:

1. Light entering a medium perpendicular to its surface passes *unchanged* in its course.

2. Light from a rare medium striking obliquely the surface of a denser medium is bent or turned *towards* the perpendicular.

3. Light from a dense medium striking obliquely the surface of a rarer medium is bent or turned *from* the perpendicular.

It is a well-known fact that a person can run faster on land than in water up to their waist, because the water is of greater density, and impedes the person's progress. So it is with light waves: they are accelerated when they pass from a dense to a rare medium and retarded when they pass from a rare to a dense medium.



Showing retardation of light.

The foregoing illustration shows a ray of light passing at right angles through a rare and a dense medium.

Air, being rare, offers so little resistance that the ray is not impeded; while glass, being denser, offers considerable resistance and slows the light. The greater the density, the slower the velocity of light, or the more effort required for the light to pass through it. Refraction may be said to be due to this fact, *viz,* that the velocity of light is less in a dense than in a rare medium.

INDEX OF REFRACTION.

All media possess a certain amount of refractive power for rays that strike them obliquely, and this is the same for each medium at the same obliquity. The angle of refraction increases as the angle of incidence becomes greater and lessens as the angle of incidence is reduced, until at perpendicularity there is no deviation or refraction of light. Other conditions being equal, the medium having the greater density will show the smaller angle of refraction, as it offers more resistance to the passage of light.

The index of refraction of a substance is determined by the ratio between the sines of the angles of incidence and of refraction, and for dense substances is found by dividing the former by the latter.

Air is taken as the standard or unit, and is called 1, toward which every other refracting medium bears a certain relation, according to the ratio above mentioned.

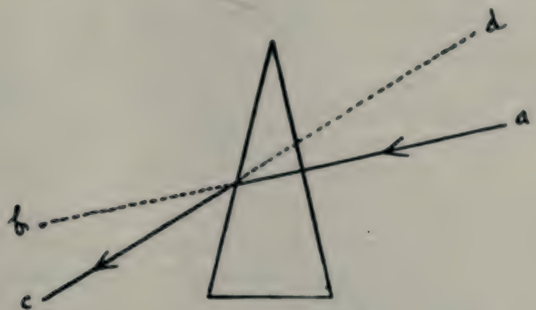
TABLE OF INDEX OF REFRACTION.

Air	1.	Crystalline Lens	1.43
Water	1.33	Crown Glass	1.52
Alcohol	1.37	Flint Glass	1.60
Aqueous Humor	1.33	Rock Crystal	1.56
Vitreous Humor	1.33	Diamond	2.49
Cornea	1.33		

REFRACTING BY A PRISM.

If the surfaces of a refracting substance are inclined to one another, as is a prism, it is obvious that a ray can never be perpendicular to both surfaces at the same time, and hence a ray can never fall upon a prism in any such way as not to be refracted.

In this figure we see a ray of light falling from the point *a* perpendicularly to the first surface of the prism, and it therefore undergoes no refraction, and if the second surface was parallel



to the first, the ray would undergo no deviation. But on emerging from the second surface, it comes into relation with the second perpendicular, from which it is refracted according to the law of passage from a denser to a rarer medium. A ray from *a* would, therefore, not proceed to *b*, but to *c*, and would virtually come from a point situated as at *d*. Rays of a moderate degree of obliquity are refracted toward the base of a prism, and this fact will enable us to understand the laws of refraction by curved surfaces, on which the main properties of the eye, as an optical instrument, depend.

In a *prism,* the two surfaces are inclined to each other, and their point of intersection forms the *refracting angle* of the prism. This point is the *apex,* while the thickest part is the *base.*

The refracting properties of a prism may be summed up as follows:

1. Rays of light passing through a prism are refracted *towards its base.*

2. Objects seen through a prism are apparently displaced in the *direction of its apex.*

These two statements at first sight may seem contradictory, but a study of the foregoing diagram will show that they are quite reconcilable.

When a prism is placed before the eye, its position is usually indicated by the direction of its base: base in means thick part of prism towards nose; base out, thick part of prism towards temple; base up, towards brow, and base down, towards cheek.

ACTION OF PRISMS.

Prisms do not converge or diverge the rays of light, and therefore they have no foci and do not form images. They simply bend the rays of light from their original course.

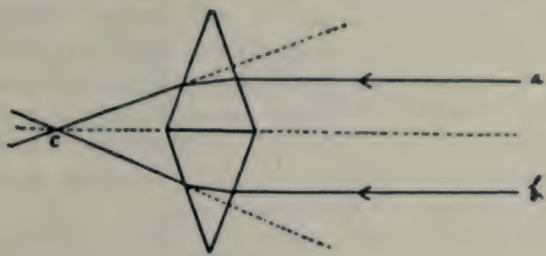
In prisms under ten degrees, the angle of deviation is equal to about one-half the refracting angle of the prism.

EFFECT OF PRISMS BASE TO BASE.

If two prisms are placed base to base, as shown in the following figure, any two parallel rays of light, as *a* and *b,* falling upon corresponding points in the surfaces, being equally refracted toward the base, would meet and cross at some point situated as at *c* on the far side.

This point may be termed the focus for the two rays; and as the reverse of every optical fact holds good, so any two diverging rays proceeding from a luminous point, as at *c,* would, in passing through these prisms, be rendered parallel, as *a* and *b.*

If the surfaces of the prisms, instead of being plane, were curved equally from the center to the edge, there would be formed an optical contrivance called a lens, which in the above case, where the bases of the prisms are joined together, would be a bi-convex lens. As a curve can be resolved into a number of small planes, it follows that a bi-convex lens may be regarded as a number of

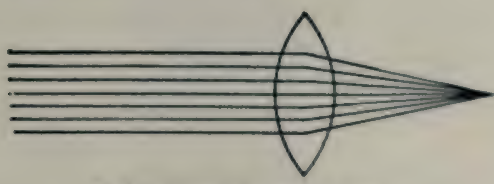


truncated prisms arranged with their bases toward the center. Prisms so arranged would refract parallel rays toward their bases; hence, parallel rays falling on one surface would be rendered convergent and tend to meet in a point at some distance from the second surface—this is called the *principal focus*, and its distance from the optical center of the lens its *principal focal distance*. Lenses are often spoken of according to their focal length, as two, four, or eight-inch lenses.

A focus is the point of a convergent or divergent pencil.

A positive or real focus is the point where rays are made to meet after refraction through a convex lens or reflection from a concave mirror.

A negative or virtual focus is the point from which rays appear to diverge after refraction through a concave lens or reflection from a convex mirror.



Positive focus of a convex lens.

Now, if the surfaces of a lens are perfectly round, being sections of a perfect sphere, it is called a spherical bi-convex lens, and the ray of light that passes directly through the center, in line with the perpendicular, is not refracted, and is called the axial ray of the lens, or *the principal axis.* In a bi-convex lens the parallel rays from infinity, coming from a given direction, will fall upon the convex surface of the lens, and, passing through, will be bent by the lens until all the rays will meet at the principal focal point, and then, passing on, will diverge; while the axial ray, which passes through the center and strikes the surface of the lens parallel to its perpendicular at that point, will pass onward without any deviation. We may also have certain rays of light striking the lens on other portions of its surface, and which pass through without refraction, as all those rays that enter the lens parallel to the perpendicular at the point of entry are not refracted. These rays are called the *secondary axes,* and all rays passing parallel to them will be brought to a focal point on each secondary axis.

THREE FORMS OF REFRACTORS.

1. When the surfaces of the refractor are parallel, it is called a *plane.*

2. When the surfaces of the refractor are plane, but not parallel (being inclined to each other), it is called a *prism.*

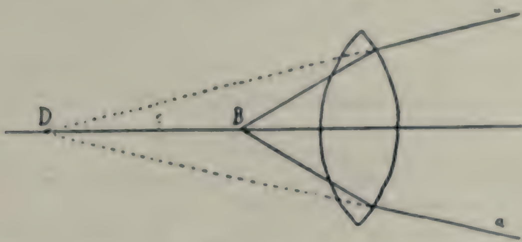
3. When the surfaces of the refractor are neither plane nor parallel, but curved, it is called a *lens.*

CONJUGATE FOCI.

Divergent rays from a luminous point situated at the principal focus of a lens are rendered parallel on passing through the lens; but rays from a more distant point are less divergent, and the refractive power of the lens is then more than sufficient to render them parallel. They are, therefore, rendered convergent to a point situated at a certain distance on the other side of the lens; and as the relationship of these points is constant and interchangeable, they are termed *conjugate*—both are *positive* and real.

On the other hand, the rays from a luminous point closer than the principal focus are too divergent to be rendered parallel by the refractive power of the lens, and consequently they emerge from the other side divergent, though, of course, in a less degree than before passing through the lens.

In this figure we see rays diverging from a luminous point *B*, which is situated on the axis of the lens and nearer to it than its principal focus *c*. If the resulting divergent rays *a a* are con-

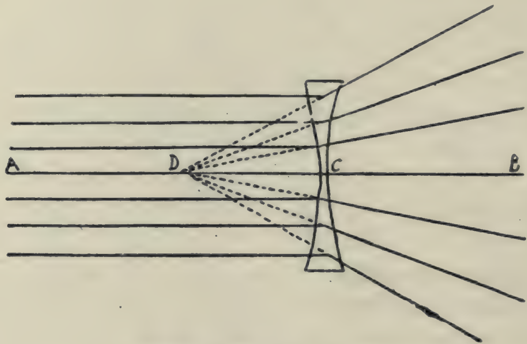


tinued backward by imaginary lines, they will meet in a point situated as at *D*, and the lines *a a* will have the optical value as if they proceeded from *D*, and not, as they really do, from *B*. The closer *B* is brought to *c*, the farther *D* recedes, and *vice versa*. A luminous point situated as at *B* has, therefore, a conjugate focus on the same side of the lens. It has no real existence, but represents the point whence the rays seem to come—it is negative or virtual.

CONCAVE LENSES.

A concave lens is thicker at the edge than at the center, and may be regarded as representing a number of prisms with their apices together at the center and their bases outward. Now, if we apply to these curved surfaces the same rules of refraction as in the case of the convex lenses, we will find that as the parallel rays emerge from such a lens they are divergent, because they are bent toward the bases of the prisms. If the lens surface be spherical, it forms a bi-concave spherical lens. This lens will so refract rays of light that they will diverge in all directions, as if they came from some point behind the lens; and it will be found that if the directions of the divergent rays are produced backward, they will meet in a point on the axis called the principal focus. But such a lens has no real or positive focus, and it is consequently called a *negative* lens.

The distance of this backward focal point from the optical center of the lens is called the negative focal distance, which may be represented by inches or dioptrics. If we represent this distance in inches, then a bi-concave spherical lens of twelve inches focal distance will cause parallel rays of light to diverge, after they have passed through the lens and been refracted, as if they came from a point twelve inches behind the lens, on the principal axis.



Negative focus of a concave lens.

The figure above represents a bi-concave lens *C*, with parallel rays from *A*, which pass through the lens and, being bent toward the bases of the prisms (of which the concave lens is composed), are made divergent, as at *B*, with a direction as if they came from the negative focal point *D*, as shown by the dotted lines. Thus, when the parallel rays strike these curved surfaces, they are bent in the same manner as when they strike the surface of the biconvex lens, but the curvature here is different, as the bases of the prisms are now outward; therefore the direction of the rays is divergent as they pass through the lens.

MENISCUS LENSES.

All lenses refract light on the same principle and in the same manner, according to the curved surfaces that are presented to the rays of light; those that are convex bringing the rays to a positive focus, and those that are concave causing the rays of light to diverge as if they came from the negative focal point, that is, behind the lens.

Let us look for a moment at what are called *Meniscus* lenses. The first one is concavo-convex, and has a negative and a positive curved surface; but the curvature of the positive surface being so much greater than that of the negative surface, the rays of light, after they pass through the lens, are brought to a positive focal point; while with the other lens, which is called convexo-concave.

the negative surface has the greater refracting power, and hence the rays, as they pass through the lens, diverge from the negative focal point.

By way of illustration, we will suppose that the concavo-convex lens above referred to has a curvature on its negative or concave side equal to a concave lens of two dioptrics, and that the curvature of the positive or convex side of the lens is equal to a

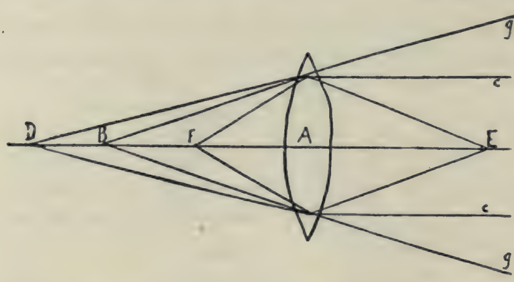
convex lens of four dioptrics; thus the positive focal power of this Meniscus lens will be equal to the difference between the two lenses; or, in other words, the strength of the convex surface will be diminished or in part neutralized by the strength of the concave surface; or the two dioptrics, taken from four dioptrics, leave two dioptrics as the strength of this Meniscus lens. As is well known, most of the lenses of the spectacles and eye-glasses of the shops, particularly lenses of low power, are ground according to this method.

The particular advantages these Meniscus (or periscopic) lenses are said to possess, are that they give much more correct secondary axes, and when adjusted to the eye yield more perfect vision through the periphery of the lens, rendering the field of vision much larger and more distinct.

ANGLE OF REFRACTION ALWAYS THE SAME.

It should be known that the angle of refraction is always the same when passing through a concave or convex lens. It will be remembered that when the luminous point is at the focal distance of a convex lens, the rays, as they emerge from the lens, are parallel; but if the luminous point is moved farther back from the lens, then we find that the rays that emerge are convergent; while if the luminous point is moved nearer to the lens than the focal distance, the rays as they emerge are divergent.

These facts are well shown in the following figure, where *A* represents a bi-convex lens whose focal point is situated at *B*, the rays from which point will pass beyond the lens in parallel lines *c c*. Now, if the luminous point is moved back to *D*, it will be found that the emergent rays are convergent, the angle of refraction being the same, and if continued would meet at *E*.



Then, again, if the luminous point be moved nearer to the lens and inside the focal point, as at *F*, the emergent rays would pass beyond the lens in a divergent direction, as the lines *g g*, the angle of refraction remaining the same as when the rays proceeded from the principal focal point.

The result with a concave lens is the same; but when the luminous body is nearer the lens than its focal point, the emergent rays are more divergent than the refractive power of the lens, and they can not be made convergent.

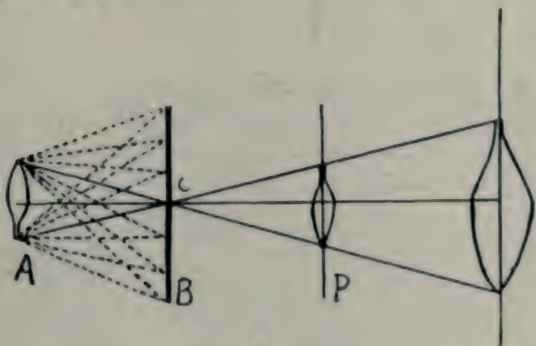
The fact of the angle of refraction being always the same is beautifully illustrated in the human eye, where the refraction of the dioptric media, taken collectively, represents a bi-convex lens of the same focal power.

FORMATION OF IMAGES.

With a clear understanding of the optical principles which have so far been stated, the student is now in a position to understand the formation of images. When you look into a looking-glass you can see yourself—you can judge of your complexion, of the condition of your hair and clothes, or you can assume one or another peculiar attitude, with the certain assurance that whatever you see in the glass is an exact optical reproduction of yourself. But you must be aware that the image you see in the glass has no material existence, can neither touch nor be touched, is neither hot nor cold, solid nor gaseous, nor can it convey any impression to any other sense than sight—it is simply your image.

If a sheet of white paper is placed six inches distant from a candle flame and a cardboard screen exactly midway between the two with a pin-hole in its center, the image of the flame will be seen on the paper. Its color, shape and movements will be accurately reproduced, but it will be inverted.

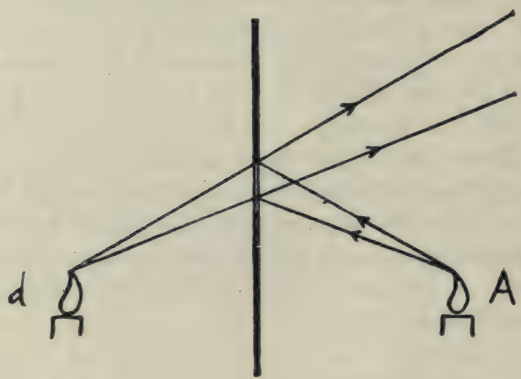
In the figure below we see numerous divergent rays proceeding from the luminous points in the candle flame *A*. Most of them are intercepted by the screen *B*, and it is evident that not more than a few rays from each point can pass through the pin-hole at *c*, and those that pass must necessarily cross there. The ray from the upper point of the flame *A* becomes the lower point on the paper *P*, and *vice versa;* and as the rays from the right cross over to the left, and those from the left cross over to the right, it follows that the image will be completely reversed. The illustration shows that if the screen is exactly midway between the candle and the paper, the image and the flame will be exactly the same size; but if the paper is placed at a greater distance, the image will be enlarged; while if it is placed nearer, the image will be diminished. A fact to be noted is that the smaller the image the brighter it will be.



If a second pin-hole is made in the screen the result will be that two images will be formed on the paper; if a third pin-hole is made, three images will result, and so on. If the pin-holes are very close together, a corresponding number of images will be formed, but they will overlap and present only the appearance of a blurred spot of light. It can, therefore, be understood that the reflection from a sheet of paper, or from any visible object, is composed of the rays proceeding from a number of overlapping images of the sun, candle flame, or any other source of illumination. With a minute aperture in a screen, all superfluous rays are cut off, and each point of the flame is represented by a point in the image, which is, therefore, clearly defined.

It will be noticed that whereas the image of the flame appears on the screen and inverted, one's own image appears to be behind the mirror and erect.

In the figure below we see diverging rays proceeding from a candle flame *A*, and falling in an oblique direction upon a plane



mirror. As the angle of reflection is equal to the angle of incidence, the rays, as they fall upon the mirror and are reflected, will continue to diverge at the same rate as they did before reflection. But if the lines are produced on the opposite side of the mirror, they will be found to meet at a point *d*, exactly the same distance behind the mirror as *A* is in front of it. The same is true of rays proceeding from other points. Hence the reflected rays seem to come from the points *behind* the mirror, and not, as they really do, from those in front. Such an image is termed *virtual*, in contradistinction to one that can be thrown on a screen and is termed *real*.

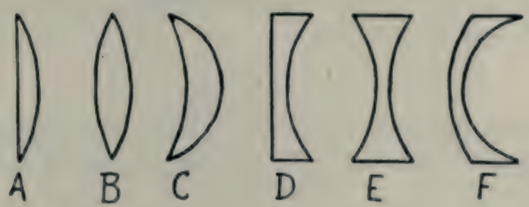
CHAPTER V.

LENSES.

A lens is a transparent substance (usually of glass) having one or both surfaces curved.

VARIETIES OF LENSES.

Lenses are of three kinds—spherical, cylindrical and prismatic. The spherical and cylindrical are either convex or concave, while the prismatic may be plain or may be ground convex or concave; and any two or all three of them may be combined together into one lens.



A, plano-convex lens; *B*, bi-convex or double convex lens; *C*, periscopic convex or concavo-convex lens; *D*, plano-concave lens; *E*, bi-concave or double concave lens; *F*, periscopic concave or convexo-concave lens.

In writing about lenses, in order to avoid the constant repetition of the words convex and concave, it is customary to distinguish lenses of the former kind by the prefix of the plus sign (+), and those of the latter kind by the prefix of the minus sign (—). + 3 D. signifies a convex lens of three dioptrics, while — 3 D. signifies a concave lens of three dioprics.

The letter *S*, or abbreviation *Sph.*, is used to denote a spherical lens; and the letter *C*, or abbreviation *Cyl.*, a cylindrical lens. If neither is mentioned, it is understood to be spherical.

If a revolving sphere be made to act as a grinding instrument and a piece of plain glass be held against it and ground on its one surface, a *plano-concave* lens will result. If both sides are ground, a *bi-concave* lens will be produced.

If the inner side of a piece of plane glass be ground on the outside of a small sphere and the outer side of the same piece of glass be ground on the internal surface of a much larger sphere, a *periscopic concave* lens is produced.

If a piece of plane glass be ground on both sides against the inner surface of a hollow revolving sphere, a *bi-convex* lens is produced.

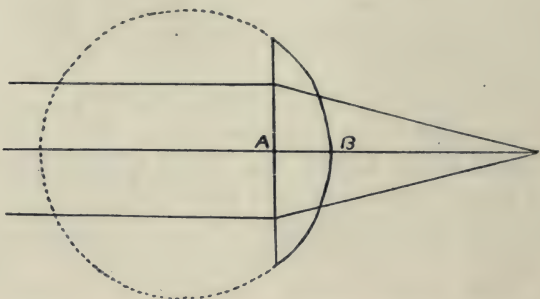
If a piece of plane glass be placed against a revolving cylinder and ground until it fits the cylinder, a *plano-concave cylindrical* lens will be produced.

If the outer side of a piece of plane glass be ground on the inner surface of a hollow revolving sphere and the inner surface of the same glass be ground on the outer surface of a much larger sphere, a *periscopic convex* lens is the result.

If a piece of plane glass be placed against the inner surface of a section of a hollow revolving cylinder, a *plano-convex cylindrical* lens will be produced.

LENS ACTION.

A ray of light will continue to travel in a straight line as long as it is perpendicular to a surface; but inasmuch as at least one surface of a lens is curved, it is obvious that a ray of light cannot strike such a surface at right angles, *except* at one minute point,



A plano-convex spherical lens and its action on light.

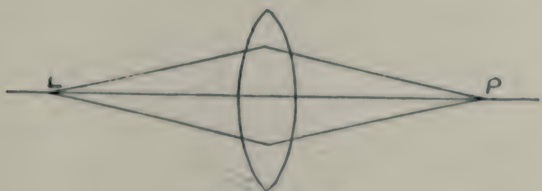
the optical center. Hence all rays of light passing through a lens are refracted or bent out of their straight course except the axial ray, which passes without deviation through the very small part of the lens where the surfaces are parallel—the thickest part of a convex lens and the thinnest part of a concave lens. In the first case, the rays are converged to a focus, and in the second case diverged; the action of a convex lens being similar to a concave mirror, and a concave lens similar to a convex mirror.

In every spherical lens there are two points (A and B), one upon each surface, through which a ray of light may pass and suffer no refraction, this being the *principal axis* of the lens; the *principal focus* is also situated on this line, where parallel rays are made to meet. The *optical center*, too, is located on this line.

CONJUGATE FOCI.

The point from which rays of light diverge and the point to which they converge are conjugate (meaning yoked together) to each other.

Rays of light diverging from L and passing through the convex lens are converged to the point P. These two points, L



Conjugate foci.

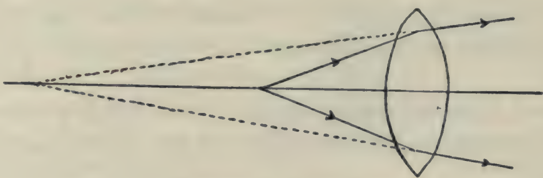
and P, bear certain defined relations to each other, and are called *conjugate foci*. They are interchangeable, and either may be taken as the location of the luminous point, when the rays will be focused and form a real image at the other.

Conjugate foci are well illustrated in the myopic eye, where the retina is situated back of the principal focus. Rays of light emerging from the retina of such an eye would be convergent and would meet at some short distance. Contrariwise, rays diverging from such distance would focus on the retina of this eye, as a myopic eye is formed to receive divergent rays and focus them on its retina. The far point of a myopic eye and its retina are conjugate to each other.

The farther away from a lens the point from which the rays diverge, the nearer to the principal focus will be the point to which they converge, until the point is so far away that the rays proceeding from it are parallel, when they will meet at the principal focus.

A lens has innumerable foci—as many as there are imaginary points on the axial ray between the principal focus and infinity.

When rays of light diverge from a point closer than the principal focus, after passing through the lens they continue divergently. There is no real focus, but the negative focus may be found by projecting these lines back upon themselves to a point on the same side of the lens from which they appeared to come.



Negative or virtual focus.

A similar condition exists in the hypermetropic eye, where the retina is closer to the crystalline lens than the principal focus of the eye. In a state of accommodative rest, the retina of such an eye would project the rays outwards divergently, and would be able to receive on its retina only convergent rays (the light being made so either by the accommodation or by convex lenses).

ACTION OF CONCAVE LENSES.

All rays of light passing through a concave lens, no matter from what distance, are refracted in a divergent form, and the focus of such a lens is always negative or virtual, and is found by projecting these divergent rays backward in the direction from which they appear to come until they meet at a point on the axial ray.

IMAGES FORMED BY LENSES.

A real image is one that is formed by the actual meeting of rays and which can be projected on a screen. Such an image is inverted and is the result of refraction by a convex lens or reflected from a concave mirror.

A virtual image has no real existence, being formed by the prolongation backward of divergent rays. It is always erect and smaller than the object, being the result of refraction by a concave lens or reflection from a convex mirror. Such an image can not be projected on a screen, but can be seen only by looking through the lens or into the mirror.

MATERIAL FROM WHICH LENSES ARE MADE.

In regard to the question of the material for the composition of lenses, and in order to understand the statements of some opticians who advertise they manufacture certain kinds of lenses, it is well to know that all lenses are made from only two materials—glass and rock crystal or pebble.

The great desideratum is to obtain a material that disperses light the least in proportion to its refractive power. Crown glass answers this purpose best, and hence should be used for all the stronger numbers. The claim for the preference for pebbles rests solely on the ground that because they are harder their surfaces polish better, and hence do not scratch so easily; but the claim that they are better for the eye rests on no good foundation. Oftentimes the so-called pebble spectacles that have been bought at a high price from some itinerant optician, and that afford so much comfort to the wearer's eyes, are found, when tested, to be nothing more than glass; so that we are compelled to the conclusion that (sometimes, at least) the superiority of the pebbles is in the imagination and not in the spectacles.

Pebble-testers are made, to determine the composition of lenses. A common, every-day test is that pebble seems colder to the tip of the tongue than glass.

It should be kept in mind that one lens of a given focus is precisely like another of the same focus, and, consequently, glasses that are advertised under various high-flown names as possessing special characteristics have really no such characteristics at all that are not common to all glasses, and the conclusion is forced that such advertisers are most likely frauds and humbugs.

EXPERIMENTS WITH A STRONG CONVEX LENS.

The chief use of lenses is to produce images. Hold a convex lens at a greater distance from a printed page than its focal length; for instance, a two-inch lens at six inches. The letters will appear inverted and diminished and as if printed on the surface of the lens. Move the lens a little closer, say to four inches; the print will still be inverted, but the letters are no longer diminished, but of their natural size. At three inches the letters are magnified, and continue to increase as the principal focus is approached—that is, at two inches, where the inverted image disappears. If the lens be held closer than its focal length, the print will appear enlarged and erect.

CYLINDRICAL LENSES.

The lenses heretofore spoken of have been spherical, equally curved in all directions, with their refractive power exactly the same in all meridians, so that the rays are either brought to a focus or diverged as from a negative focus.

But for the purpose of correcting different errors of refraction in the eye, there are found in all complete cases of trial-glasses sets of lenses whose action is quite different from that of those hitherto described. These are called *cylindrical* lenses, as they are practically segments of a cylinder with the axis of the cylinder at right angles to the refracting surface; they are generally plane on one side, with the refracting surface on the other, and may be either convex or concave.

Cylindrical lenses act only upon the rays of light that fall in the meridian at right angles to the axis upon which the glass is ground.

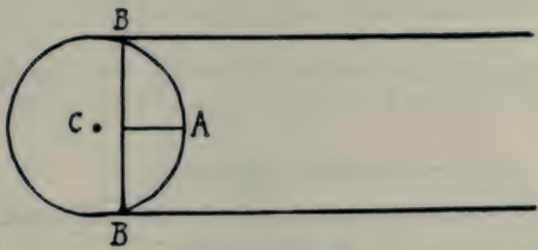
In studying the action of cylindrical lenses we must consider chiefly all the rays as passing in two principal planes at right angles to each other. While the light also passes in any number of intermediate planes, yet the rays are so bent that in the convex cylindrical lens they will focus at a positive point, there forming simply a line, and not a single point, as in the case of a spherical lens.

The two principal planes of the eye are generally vertical and horizontal, and it is to be remembered that the principal planes are always at right angles to each other, and may be at any degree of the arc of a circle. If we have a glass whose refractive power will be only on the rays of light of one meridian, the rays that pass in the meridian at right angles to that will pass parallel and unrefracted.

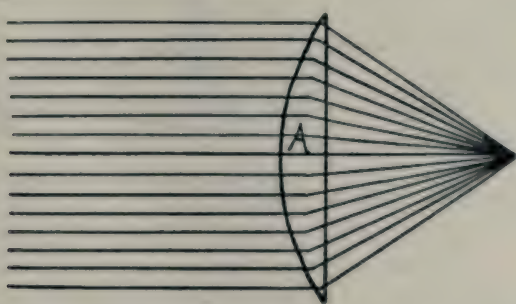
As has just been stated, a cylindrical lens is one that is a section of a cylinder. If we take a cylinder of glass, with the axis running directly through its center, and cut off a section parallel to this axis, the rays of light that pass through in a plane that is the same as the axis will not be refracted; but all those passing at right angles to that plane will be either convergent or divergent, according to the refracting power of the glass and the radius of its curvature.

LENSES

In this diagram can be seen the end of the cylinder of glass with its axis at *C*. If a section is made at *B*, the part cut



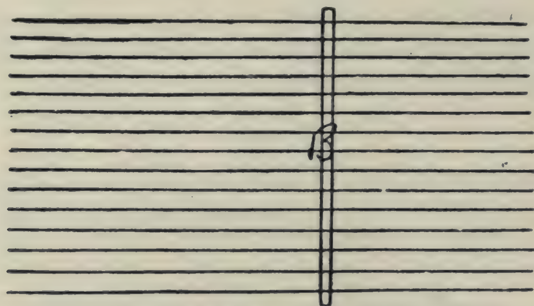
off will form a plano-convex-cylindrical lens. A section made through this at *A* will present the surface of a rectangle, and all the rays in that plane will strike the glass parallel to its perpendicular, and will not be refracted.



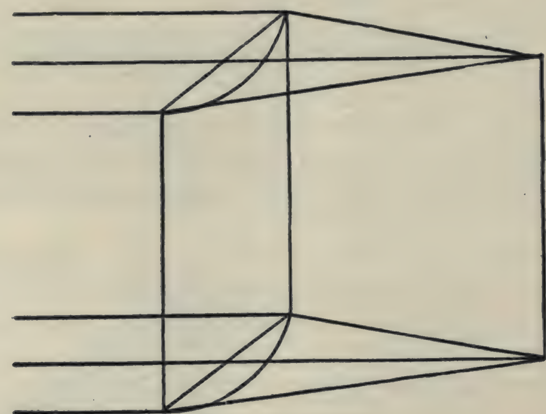
The action of such a lens is illustrated in the above diagram, which shows how parallel rays of light are refracted when passing in a plane at right angles to the axis of the glass.

While at *B* the parallel rays of light are unrefracted when passing in a plane coincident with the axis.

Hence we have this rule, that a cylindrical lens will converge or diverge only those rays of light that pass at right angles to its



axis, according to the refractive power of the lens; consequently, the refracted rays of a cylindrical lens are never brought to a



focal point, but form a straight line on a screen placed at its focal distance.

COMPOUND LENSES.

Glasses are frequently ground spherical on one side and cylindrical on the other, such glasses being called *compound cylindrical lenses;* or they may be ground convex-cylindrical with the axis in a certain direction on one side, while the other side may be ground concave-cylindrical with the axis in a different direction, such lenses being known as *cross-cylindrical* lenses.

And a sphere or a cylinder may be combined with a prism, or all three may be ground together, giving five forms of compound lenses, as follows:

1. *Sphero-cylinder*, in which both elements may be variously convex or concave.

2. *Sphero-prism*, in which the sphere may be either convex or concave and ground on one surface of the prism.

3. *Cylinder-prism*, in which the cylinder is ground on one surface of the prism, either convex or concave.

4. *Sphero-cylindro-prismatic*, in which the sphere is ground on one surface of the prism either convex or concave, and the cylinder on the other surface either convex or concave.

5. *Cross-cylinder*, in which one surface is convex-cylindrical and the other concave-cylindrical.

THE ACTION OF PRISMS.

The educated optometrist should thoroughly understand the action of prisms singly and combined with convex or concave glasses. As has already been shown, a prism deflects light toward its thick edge, or, in other words, an object seen through it has its position apparently moved toward the side of the thin edge.

If an object is placed directly in the middle line in front of a person, so that a straight line drawn from it would strike the root of the nose, and if then one eye be closed and a prism held before the open eye, the position of the object will be apparently altered. If the prism be placed in front of the eye, base in, the object will be moved outward; while, on the other hand, if the prism be placed over the eye base out, the object will be moved inward. The amount of displacement will, of course, depend upon the distance of the object from the eye and the degree of the prism. A prism of the proper degree with its base in will change the apparent position of the object from the middle line directly in front of the nose outward to a point directly in front of the eye, provided always that the eye is directed straight forward and its convergence is at rest.

A similar prism placed in a like position before the other eye will have a similar effect, thus resulting in placing the two objects directly in front of each eye, and single vision of the object will be afforded without the slightest effort of convergence. The object, however, being somewhat close to the eyes, calls for an effort of the accommodation in order to be clearly seen, and then we have a condition in which there is tension of the accommodation with relaxation of the convergence, a condition which could not be long maintained without fatigue, on account of the well-known correlation existing between the functions of accommodation and convergence. If, now, in this condition, a pair of convex lenses, of a focal length of the same number of inches as the object is placed from the eyes, be added to the prisms, they will remove the necessity for any effort of the accommodation, and, as the prisms had removed the necessity for convergence, the object is, consequently, seen for an indefinite period without any muscular effort on the part either of the accommodation or convergence. When a convex focus is ground upon a prism as above described, the combination is called "orthoscopic" spectacles.

ORTHOSCOPIC LENSES.

It will be manifest on a little reflection that every lens must have a corresponding prism, which would stand in "orthoscopic" relation to it. In the stronger numbers of lenses the degree of the corresponding prism would be so great, and would add so much to the weight and thickness of the glass, as to practically prohibit their use, and limit the combination to the weaker numbers. Practically these glasses are not used very much, perhaps not as much as they deserve to be.

The following table, which is only approximate, gives the number of the convex glass, with the degree of the corresponding prism:

Lens.	Prism.
.50 D.	1½°
1. D.	3°
1.25 D.	4½°
1.75 D.	6°
2.25 D.	7½°
3. D.	9°

The test of such glasses being perfectly "orthoscopic" is that the two lenses, when fixed in their frame, should cast only a single image upon a card placed at their focal length; it is at once evident that this requires careful adjustment.

The reason why only one image is formed by orthoscopic lenses is because these prismatic convex lenses are, or may be considered to be, eccentric portions of one very great lens, as shown in the accompanying diagram:

These portions representing the orthoscopic lenses are the parts through which the eyes would look if one large lens was held up before the face, with its center opposite the root of the nose; and consequently, as the large single lens produces only a single image at its focal point, so should its two eccentric portions produce only a single image at the same point.

TINTED GLASSES.

Tinted glass, which is sometimes used for spectacle lenses, presents a varying density of tint in different parts, corresponding to the varying thickness of the glass in its different parts. In the case of concave glasses, which are thinnest in the center, this is perhaps rather an advantage than otherwise; while in the case of convex glasses, which are thickest at the center, the deepened tint at this point amounts almost to a prohibition of their use. In this latter case, however, the inequality of the tint may be avoided by making use of a plano-convex lens, to the plane surface of which a thin plate of tinted glass is cemented by means of Canada balsam.

Tinted glasses with parallel surfaces (that is, without any refractive power) are in common use to temper the light which reaches the eye; they are made either with plane surfaces, like window-glass, or with curved surfaces like watch-glasses, these latter being coquilles. The favorite color for tinted glasses was formerly green, on account of its similarity to the color of the grass and the foliage of the trees. Green was gradually superseded by blue (the color of the sky), which is still much used. But those in most common use are a neutral tint, called London-smoke, preferable to either green or blue. Glasses of an amber tint are also kept in the shops; they are known as "shooting spectacles," and are ground to a dull surface, except at the central portion

The choice being narrowed down to blue and smoke, the question occurs, which is the better? Where true photophobia exists—that is, a general intolerance of light—smoke glasses are the best; otherwise, where the asthenopia is caused by the eye's intolerance of reflected light (not a pure photophobia), blue glasses are preferable.

The reason for these choices may be stated as follows: Red is the color most stimulating and irritating to the eye, causing asthenopia when viewing objects illuminated by reflected light in which red is the predominating color. Smoke simply decreases the volume of light, but does not arrest one color more than another. Blue, however, fuses with the red and makes a new tint that is agreeable to the eye.

Amber glasses afford protection against the chemical rays of the spectrum, counteracting chromatic aberration and softening dazzling reflections. Amber lessens photophobia and irritation, does not provoke spasm of accommodation, and at the same time increases the sharpness of the image.

Perhaps a word might be spoken here of one of the disadvantages of the coquille form of smoke glasses; and that is, their liability to have a concave focus—and it is often very objectionable. If the two surfaces of the glass were exactly parallel in every part, there could be no focus; but it can be understood at a glance that it is much more difficult to make the two surfaces parallel in coquilles than it would be in plane glasses, and, as a result, persons who are supposed to be wearing plane smoke-glasses are really looking through concaves, which often results in straining the eyes, especially if the person be hypermetropic.

Coquille spectacles and eyeglasses, colorless and tinted, are made also in the Meniscus form (with positive focus) and in the concave-convex form (with negative focus). Owing to the shorter radius of curvature of the concave surface turned toward the eye, these glasses are more perfectly periscopic than those commonly sold under that name.

SPECTACLES FOR PROTECTION.

Spectacles afford, to a greater or less extent, protection against mechanical injury, and in some certain trades it is only by the use of such special protectives that the liability to grave accidents to the eyes can be averted. Millers have long been in the habit of wearing large spectacles fitted with thick window-glass when employed in the dangerous work of dressing mill-stones. Protective spectacles of mica are especially to be recommended for miners, quarrymen, stone-cutters, boilermakers, and others engaged in similar dangerous employments. Goggles of finely woven wire gauze, generally with the fronts glazed with tinted plane glass, are used by railway travelers and others as a protection against flying sparks; goggles made of glass bent to a curve and furnished with cloth-covered rims to fit closely around the margins of the orbits are sometimes used as a protection against dust in driving, and especially in automobiling.

USES OF GLASSES.

Besides being mere protectives, as just mentioned, the purpose of spectacles and eyeglasses is principally to supplement impaired accommodation (as, for instance, the convex glasses used in presbyopia and in accommodative paresis and paralysis), to relieve the accommodation of an excessive burden by supplementing deficient refraction (as, for instance, the convex glasses used in hypermetropia), and to correct asymmetrical refraction (as, for instance, the convex and concave-cylindrical glasses used in astigmatism). These several effects are, moreover, often variously combined, as in the use of strong convex glasses in reading (by hypermetropes with defective accommodation), of partially correcting concave glasses, or, perhaps, of weak convex glasses in reading (by myopes with defective accommodation), and of glasses of asymmetrical refraction (in compound and mixed astigmatism and in presbyopia or other accommodative defect occurring in connection with astigmatism).

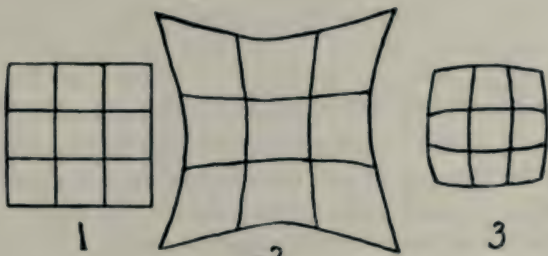
Objects viewed through convex glasses appear larger than do the same objects when their images are focused by the exercise of the accommodation, and, conversely, objects viewed through concave glasses under accommodative tension appear smaller than do the same objects when viewed without the exercise of the accommodation. Hence, a presbyope using convex glasses in reading sees the print not only clearer than without glasses, but also larger than it appears to an emmetrope under normal exercise of the accommodation. So, also, an hypermetrope wearing convex glasses constantly sees all objects larger than when he views them without glasses, and a myope using concave glasses in reading sees the print smaller than when he reads without glasses. In hypermetropia, however, the actual size of the retinal image is smaller and in myopia it is larger than in emmetropia; and it is a fact now well established that both hypermetropes and myopes wearing neutralizing glasses at the usual distance from the eye, see objects of about the same apparent dimensions as does an emmetrope without glasses.

POSITION OF LENSES AS REGARDS NEARNESS TO EYES.

A convex spectacle lens is increased in effective power by moving it farther from the eye, and, conversely, a concave lens loses in effective power with any increase in its distance from the eye. The correct rule of practice is to mount the glasses as near as possible to the eyes, allowing sufficient room for the free play of the eyelashes. A distance of about one-half inch from the vertex of the cornea fulfils this condition in most cases, and at the same time allows the correcting lens to be placed almost exactly at the anterior principal focus of the eye, in which position of the glass the retinal image, whether in hypermetropia or in myopia, becomes practically equal in size to the image of the same object when focused by an emmetropic eye. Whenever an hypermetrope inclines to remove his convex glasses to a greater distance from the eye than one-half inch, it may be assumed that the glasses are somewhat too weak to fully correct his hypermetropia, and, conversely, when a myope inclines to wear his concave glasses at a greater distance from the eye than one-half inch, it may be assumed that the glasses are too strong. This particular mode of correcting the effect of badly selected glasses in distant vision is but rarely adopted, except in the presence of defective accommodation, as, for instance, by elderly hypermetropes or myopes, and especially by persons who have undergone an operation for cataract. In presbyopia it is not uncommon practice to slip the convex reading glasses far down toward the tip of the nose, in order to make a weak glass do the office of a stronger glass in improving the distinctness of the print, and also in increasing its apparent size; in this position of the glasses it is also easy to look over them at distant objects.

The increase or diminution in the apparent size of objects viewed through a convex or concave lens is not uniform in all parts of the visual field, but is notably greater at its periphery than at its center. Thus a large object viewed centrally through a spherical convex lens is seen more highly magnified in its peripheral than in its central portions; a square, for example, whose angles are more distant from the center than is the middle of each side, is seen as if bounded by curved lines with their convexity turned toward the center of the field. The same square when viewed through a concave lens is seen diminished in size, but most diminished in its peripheral portions, so that it appears as if bounded by curved lines with their concavity turned toward the center of the field.

The figures below illustrate at *2* and *3* the distortion under which a large square figure (*1*, a window, for example) is seen



1 2 3

through a convex and a concave lens respectively. It will be observed that the distortion of the smaller squares increases from the center toward the periphery of the field.

It has been often remarked that myopes, in selecting concave glasses, are very apt to err by making choice of glasses of somewhat too short focus, which cause objects seen through them to appear very sharply outlined. This phenomenon appears to be the result of the chromatic aberration of the eye, causing the object, when viewed through a concave glass under a full correction for the most highly refrangible rays (violet) of the spectrum, to be seen as if bounded by a very narrow red border, instead of by a broader violet fringe, as when the eye is focused for the least refrangible rays (red). If a distant point of light be viewed by an over-corrected myopic eye through a piece of cobalt-blue glass the light will appear blue with a narrow red halo; if the eye is under-corrected by its concave glass, the light will appear red, with a broader violet halo.

DISTORTION CAUSED BY CYLINDERS.

A convex or concave cylindrical lens, as used for the correction of astigmatism, simply elongates or shortens the retinal image in a direction at right angles to the axis of the lens; thus the relation of the two diameters of the object appears altered, a circle appearing elongated or shortened to an ellipse, etc. The distortion from this cause in regular astigmatism, when the direction of the two principal meridians happens to be asymmetrical in the two eyes, may give rise to such difference in the two retinal images as to evoke a great variety of stereoscopical illusions from the fusion of the two impressions in binocular vision; illusions of this kind are, however, very soon corrected by experience, as the wearer of the cylindrical glasses becomes accustomed to the new conditions.

CONVERGENCE AS INCREASED OR DIMINISHED BY SPHERICAL LENSES.

Incidental to the action of concave and convex spectacles in modifying the exercise of the accommodation is the effect which they exert upon convergence as associated with accommodation. Convex glasses, by relieving the accommodation of a part of its load (as in hypermetropia), exert at the same time a positive effect in diminishing the convergence which stands in correlation to it; and consequently they (convex lenses) rank first among the therapeutic agents at our disposal for arresting the development of convergent strabismus, and even, in many cases, for its cure. Concave glasses, on the other hand, by increasing the demands made upon the accommodation in near vision (as in myopia) evoke also increased action of the internal recti muscles with a corresponding relaxation of the external recti, and thus afford relief in many cases of muscular asthenopia and of crossed diplopia, and even of divergent strabismus.

Spectacles, whether convex or concave, may be so mounted as to exert also a direct action upon convergence, by what is known as *decentering*—that is, by mounting the lenses so that the optical center of the lens is not directly in front of the pupil. This effect may be developed accidentally, as a result of imperfect centering of one or both glasses, and may then be attended with more or less harmful consequences; or it may be produced designedly, and applied with advantage to the treatment of muscular insufficiency.

DECENTERED LENSES.

A decentered lens acts as a sphero-prism or a cylindro-prism when the rays of light pass through any point except its optical center; and the farther removed from this center, the greater the prismatic effect produced. The distance from the point looked through to the optical center is the measure that the lens is decentered.

In the use of prisms, when their bases are turned toward the nose, they relieve the internal recti muscles; in order to produce the same effect with decentered lenses, the thickest part of the lens must be nearer the nose than it would ordinarily be Convex lenses, in which the optical center is at the thickest part, are therefore carried toward the nose; or, in other words, the lenses are "decentered inward." Concave lenses, in which the optical center is at the thinnest part of the lens, are for the same reason, carried away from the nose toward the temple; or, in other words, such lenses are decentered outward.

Where lenses are to be used only for reading or other close work, and where there is a constant effort required from the convergent muscles, they may be decentered as described above (the convex in and the concave out) without any resulting harm, and perhaps with some advantage.

But if such decentered lenses are of advantage when specially prescribed, they produce a greater amount of harm when not required; and unless there is some reason for decentering a lens, and unless it is decentered in the particular way the person requires, the optical center should be at the place where the line of sight will pass through it, which may be just at the center in distance glasses and a little to the inner side in reading glasses.

It is important not only that the optical center should not be too far in or out, but that it should be at the proper level, and that the two optical centers (of the two lenses composing a pair of spectacles) should both be on the same level. If one is higher or lower than the other, the prismatic effect will be produced on the superior and inferior recti muscles, causing one eye to look more up or down than the other, and, the eyes naturally being intended to look on the same level, such deviations may give rise to considerable inconvenience and discomfort, and thus entirely defeat all the benefit that might otherwise be derived from a carefully adjusted pair of lenses. Such improper decentering is commonly found in cheap spectacles. We sometimes see an individual wearing his glasses with one side higher or lower than the other; may not such a person be trying to overcome the discomfort produced by such an improperly decentered pair of glasses? Every pair of lenses should be carefully tested to ascertain if the optical centers are properly placed.

RULE FOR DECENTRATION.

For every decentration of 10 mm. there will be as many degrees of prismatic power as there are dioptres of refractive power.

A 1 D. lens decentered 10 mm. would afford 1° prismatic power combined with the 1 D. sphere. A spherical lens having equal power in all meridians, the prism value obtained will be the same no matter in which direction the lens is decentered, up, down, in or out.

Illustrations:

+ 2	10 mm.	+ 2 D. $\bigcirc$ 2° Prism
+ 4	5 mm.	+ 4 D. $\bigcirc$ 2° Prism
+ 4	2.5 mm.	+ 4 D. $\bigcirc$ 1° Prism
+ 1	2.5 mm.	+ 1 D. $\bigcirc$ ¼° Prism

Theoretically, there is no limit to the amount of decentration; but practically it is greatly limited by and entirely dependent on the size of the uncut lenses. If a large lens is desired, the amount of lateral decentration would not be much more than 3 mm., and vertically about twice as much. Therefore, it becomes evident that in weak lenses the prismatic effect that can be obtained is but slight.

The statement that a spherical lens can be decentered in any direction with equal effect does not apply to cylinders. Decentration of a cylinder in the meridian of its axis produces no prismatic effect; but in the meridian at right angles to its axis the prism value developed is the same as if the cylinder was a sphere.

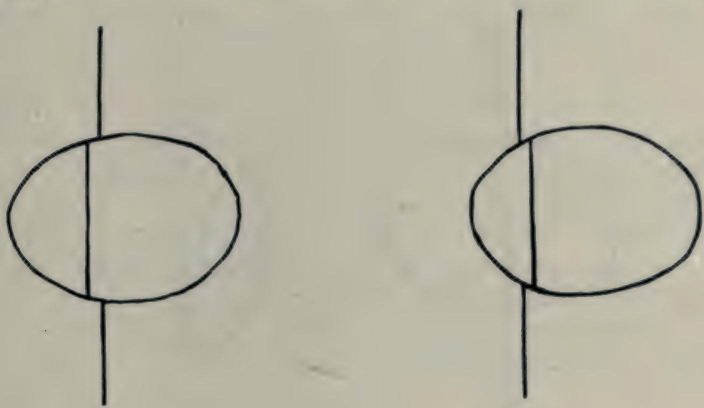
In estimating the prism value of decentered sphero-cylinders, each surface should be considered separately and then combined.

If the decentration is in the meridian of the axis, the value of the sphere only is involved.

If at right angles to axis, the full amount of the dioptric value of both lenses is considered.

HOW TO FIND THE OPTICAL CENTER OF A LENS.

The best way to locate the optical center of a lens is to look through the lens at a straight line on a card, the line being long enough to be seen through the entire lens, and also above and below it. If you look at the line through the lens at any part except its optical center, the part of the line seen through the lens will not seem continuous with the parts of the line seen above and below it.

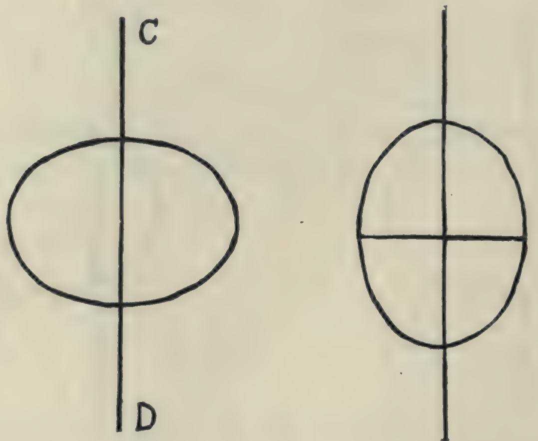


1 2

The above illustrations show this interruption of the line—figure 1 showing it as it occurs in a convex lens, the portion seen through the lens seeming to be carried away from the optical center, while figure 2 shows it as it occurs in a concave lens, where the portion of the line seen through the lens seems to be carried toward the optical center. But if you look at the line through the optical center of the lens, it will appear as one continuous line above the lens, through it and below it. Hence, the rule is to move the lens until you make the line continuous, when you will draw a line with ink directly across the face of the lens, exactly over the line seen through it, as shown in the first figure in the following diagram:

Having now determined one line, *C D*, in the above figure that is continuous, we know that it passes through the optical center, and we then turn the lens so that this line *C D* shall be at right angles to its former position. We then repeat the same steps as before, moving the lens until we have a straight, continuous line above, through, and below the lens, which we mark with ink, as before, when we know we have another line that passes through the optical center of the lens. Now, the intersection of these two lines is the point of location of the optical center of the lens.

The optical center of a lens is at the central part of the lens, at which point both surfaces of the lens are parallel, and, conse-



quently, rays passing through this point do not suffer any refraction at all. As we pass from the optical center, the two surfaces of the lens begin to incline more and more, and rays are refracted more and more; the farther from the optical center that a ray passes, the more it is refracted.

COMPOUND PRISMS.

Instead of cutting out two spectacle lenses from a peripheral zone of a very large lens (as in the illustration of orthoscopic lenses on a previous page) it is found to be quite as convenient and much less expensive to grind the required convex or concave focus upon one side of a prism, while upon the other surface of the prism a cylindrical lens may be ground if required for the correction of any existing astigmatism. Such glasses are sometimes used in correcting optical defects when they are complicated by insufficiency of the internal or external recti muscles, and would thus come into advantageous use in many cases of muscular asthenopia, and of diplopia of moderate grade, even when dependent upon paralysis of one of the recti muscles; but in well-marked cases of strabismus they are seldom of any benefit.

The decentering of a spherical lens, either convex or concave, necessarily gives rise to some distortion of the retinal image, and the greater the decentering the more pronounced will be the distortion. This is shown in the figures on page 119, where the small square at the sides and the larger square at the angles are drawn as they are seen through peripheral portions of a convex or a concave lens. Besides this, the several pencils of rays, after refraction by a decentered lens, are no longer homocentric (*homocentric* is derived from two Greek words, and means "having the same center"); that is, they no longer converge toward or diverge from a focal point, but pass through two so-called focal lenses. In other words, a decentered spherical lens always gives rise to some degree of astigmatism, which in some cases may be so great as to require correction, which can be done by using lenses of a plano-convex or a plano-concave form, and grinding a cylindrical surface upon the plane side.

When prismatic glasses with plane surfaces are mounted with their bases inward or turned toward the nose, they relieve the internal recti muscles of a part of their work in convergence, and may also restore binocular vision at a distance in cases of crossed diplopia, dependent on very slight divergence of the visual axes. When they are mounted with their bases outward, or turned toward the temple, they are applicable in some cases of insufficiency of the external recti muscles and of preponderance of the internal recti, as in the homonymous diplopia which is sometimes observed in low grades of convergent strabismus. A prismatic lens, mounted with its base up or down before one eye only, may be used to neutralize the effect of a slight upward or downward deviation of the eye before which it is worn, or the correction may be divided between the two eyes by making use of two prisms—one mounted with its base upward and the other with its base downward. Prisms are not usually worn stronger than eight degrees, on account of the conspicuous colored fringes due to chromatic dispersion.

PROPER FITTING OF LENSES.

The proper effect of any spectacle lens can only be obtained, as has already been shown, when the lens is accurately centered in front of the pupil; and another important condition is that the plane in which the lens is set shall be perpendicular to the direction of the visual axis. The distance between the centers of the two lenses of a pair of spectacles intended to be worn for distant vision should therefore be exactly equal to the interpupillary distance, and in the case of reading glasses, where the visual axes are made to converge toward the printed page, the distance between the centers of the two lenses should be somewhat less than the interpupillary distance.

Furthermore, the two lenses should be set in one and the same plane, perpendicular to the direction of the visual axes; for example, vertical in the case of glasses to be worn for distant vision, while they should be tipped forward in spectacles which are to be used for reading. Strictly speaking, the lenses of reading spectacles should also be inclined a little toward each other, so as to maintain the perpendicularity of the lenses to the visual axes when they are directed toward each other, as in the act of convergence.

TILTING OF LENS CAUSES CYLINDRICAL EFFECT.

Whenever a convex or a concave spherical lens is set obliquely to the direction of the visual axis, its refractive power is increased, though in a very different degree, in all its meridians; the increase being greatest in the meridian corresponding to the plane of the arc through which the lens is rotated, and least in the meridian of the axis about which the rotation takes place. In the case of a convex or a concave cylindrical lens rotated about its axis, the increase in refractive power varies from a maximum in the meridian at right angles to the axis, to zero in the meridian of the axis. When rotated about the meridian at right angles to its axis, a convex or concave cylindrical lens shows also a positive increase in refractive power, though in a lesser degree than when it is rotated about its axis.

It follows that a tipped spherical lens becomes practically equivalent to a (somewhat stronger) spherical lens with a cylindrical lens added to it, and that in the case of a sphero-cylindrical lens the special effect of the cylindrical surface may be either increased or diminished, according as the compound lens is rotated about one or the other of its principal meridians. A tipped concave spherical lens may be occasionally utilized in distant vision in myopia, with astigmatism of a low grade, when the ocular meridian of greatest refraction happens to be vertical or very nearly vertical, and a vertically-mounted convex spherical lens may be given for reading when the ocular meridian of greatest refraction happens to be exactly or nearly horizontal. A familiar instance of such a correction in myopia is seen in the not infrequent preference given to a tipped concave spherical eyeglass mounted in a vertical position in a spectacle frame. So, also, after an operation for cataract, a sphero-cylindrical lens, with axis horizontal, may be required to raise distant vision to its maximum, although for reading a spherical glass may be preferred, on account of the augmented refraction in the vertical meridian incident to the downward directions of the visual axes.

Again, in myopia with astigmatism, when the ocular meridian of greatest refraction happens to be approximately horizontal, the wearer of concave spherical glasses may learn the trick of looking obliquely through his glasses, either to the right or to the left, and may thus add materially to his acuteness of vision, though at the cost of acquiring an awkward carriage of the head. So, also, an hypermetrope with some degree of astigmatism, when the ocular meridian of greatest refraction happens to be approximately vertical, may similarly get a better correction from his convex spherical glasses by looking obliquely through them to one side.

A myope, wearing concave glasses of a power sufficient to fully correct his myopia, is very apt to look obliquely to one side in order to improve his vision for the vertical lines of a distant object, and he may at the same time contract the opening of the eyelids in order to improve his vision for horizontal lines. In hypermetropia this habit is but rarely acquired, for the reason that here the accommodation is generally brought into exercise to supplement the effect of the glasses, but in aphakia, owing to the total loss of accommodative power, it is oftentimes made use of

MONOCLES.

Caprice and fashion have sometimes dictated the wearing of a single eyeglass, carried at the end of a riding whip or a fan, or worn suspended by a cord; in the latter case the glass is held in front of the eye by a contraction of the orbicularis muscle upon its rim in a singularly awkward and inconvenient fashion. This is known as a monocle (one eye).

SPECTACLES AND EYEGLASSES.

Binocular (two eyes) glasses may be divided, according to the way in which they are held before the eyes, into three groups: First, eyeglasses held in the hand, and which are known as lorgnettes; second, those held in place by means of a spring which pinches the nose, the French *pince-nez;* and third, spectacles proper, which are held in place by means of temples or side-pieces, passing above and behind the ears. To these three principal types may be added a fourth, now disused except in the case of protective goggles, in which the glasses are held in place by means of tapes or an elastic band passing around the head above the ears.

The several parts of a pair of spectacles are (1) the rims in which the glasses are mounted; (2) the bridge, or nose-piece, by which the rims are connected and supported upon the bridge of the nose; and (3) the side-pieces, or temples, by which the spectacles are held in place upon the head. The size of the rims and the length of the bridge should be so proportioned as to conform both to the interpupillary distance, in order that the wearer may look through the centers of the glasses, and to the width of the face, so that the side-pieces may touch but not press too tightly against the sides of the head.

FITTING SPECTACLES.

In fitting spectacle frames, in the case of great width of the face, larger rims are generally required than when the face is narrow; any variation from the usual proportion between the interpupillary distance and the width of the face may generally be met by varying the length of the bridge. In order to properly fit the face, it may sometimes be necessary to select a frame in which the distance between the centers of the rims is a little greater or a little less than the interpupillary distance; but in such a case care should be taken in setting the glasses to preserve the proper distance between the centers.

SPECTACLE BRIDGES.

The bridge should be shaped to fit the nose and partially to encircle it; noses, however, differ very greatly in prominence and thickness, so that no single type of bridge is suited to all cases. The "hoop" bridge is one of the older forms, and is suited to noses of considerable thickness and prominence; the hoop may lie in the same plane with the glasses, or it may be turned forward at any desired angle. The modified form is now more commonly used than the plain hoop, and, like it, may be set at any required angle to the plane of the glasses. These forms are well suited to noses of some prominence, but in other cases they fail to support the glasses at the proper height, or at a sufficient distance from the eyes to avoid contact with the eyelashes. To obviate this serious defect in the hoop bridge, two very useful modifications have been recently introduced, *viz.*, the twisted (or "snake") bridge, and the "saddle" bridge. The so-called X bridge and the K bridge have been extensively used in frames of very light weight; they are, however, of less general applicability than the other forms.

A perfect bridge should present a rather broad surface of contact with the nose, and special care should be taken to secure an accurate and easy fit; in some rare cases it might even be worth while to make a cast of the nose upon which to mould the bridge. Bridges of the X and K patterns, as usually made from thin wire, are apt to cut the nose. A gold bridge is often to be preferred even when the other parts of the frame are made from steel, as being more easily moulded to the nose and free from liability to rust; a recent improvement (if improvement it can be called, as it is open to many objections,) consists in the application of a lining of fine cork to the hoop or saddle bridge.

TEMPLES.

The side-pieces, or *temples*, should be slightly bowed to fit the sides of the head; they should be of at least sufficient length to reach a little behind the ears. But best of all are the hook, or riding-bow temples, which are made of thin and very elastic wire bent downward in an easy curve behind the ears. By a recent invention, consisting in the introduction of delicate, spirally wound wire in the side-pieces, near the proximal ends—that is, near the joint—the flexibility of hooked temples has been increased.

The several parts of a spectacle frame should be nicely proportioned to each other. In the case of spectacles with single temples, the bridge should be of sufficient stiffness to maintain its shape unaffected by the lateral spring of the side-pieces. Only when hooked temples are used is it advisable to make all parts of the frame of very light weight.

Fashion has played its part in prescribing the form of spectacle lenses; the original shape was doubtless circular, a form still occasionally seen in spectacles, but more frequently in eye-glasses. The shape now generally preferred is a nearly regular oval, but with considerable variation in the proportion of the two principal diameters.

Pantoscopic glasses, so called, have the upper part of the rims flattened, in order to permit the wearer of reading glasses to see over them in looking at distant objects; the lenses are also set, as a rule, obliquely to the direction of the side-pieces, but perpendicular to the visual axis in reading.

BI-FOCAL LENSES.

In some forms of ametropia, with deficient accommodation, it is often convenient to mount two half-lenses in each rim, the upper half (convex or concave) of a focal length suited to the correction of the actual hypermetropia or myopia; the lower half, of the focus needed for reading. A similar effect is obtained, though somewhat less perfectly, by grinding the upper and lower halves of the same lens to different radii of curvature(bi-focal lenses). Benjamin Franklin is said to have worn double focus lenses, the upper half concave to correct his myopia, and the lower half convex to correct his presbyopia.

Recently several improvements have been made in the double-focus glasses; in one case a crescent-shaped piece is cut from the lower part of the lens and replaced by a similarly shaped piece of lens of the required focus for reading. In the other case, in the so-called lenticular glasses, the necessary extra strength required for reading is added in the shape of a convex lens, ground very thin and cut in the shape of a crescent, and cemented firmly on the lower portion of the lens.

Many recent improvements in the manufacture of bi-focal lenses have given us the so-called *invisible* bi-focals, as shown in the "Bisight" and "Kryptok," which are now so extensively advertised, as appealing to persons of refined tastes.

Another useful arrangement consists in mounting the reading correction in a separate frame (extra fronts) to be hooked upon the front of the spectacles that are worn for constant use.

EYEGLASSES.

Eyeglasses of the *pince-nez* pattern have been used since an early period in the history of spectacles, but their construction has been greatly improved within the past ten or twenty years. In an old painting, in one of the European galleries, an elderly bishop is represented as reading through a *pince-nez* set very low upon the nose; the rims of the glasses are circular, and the connecting piece seems perfectly rigid. This rigid construction and the manner of wearing them low down upon the nose explain the objection formerly made to them, as liable to compress the nostrils and interfere with the breathing, and so impart a nasal quality to the voice. A *fac-simile* of that portion of the painting containing this head has lately been reproduced in color in one of the publications of a London society.

In the older forms of eyeglass the centers of the glass stand much too near together, and the glasses themselves are very apt to tip forward in a way that is sometimes very detrimental to the optical effect intended to be obtained from them. In many cases, also, they stand so near to the eyes as to allow insufficient room for the play of the eyelashes, and whenever the nose is unsymmetrical, one glass is sure to stand higher than the other.

In the recent eyeglasses of improved construction these defects are, to a noticeable extent, obviated. Thus most of the modern eyeglasses have some form of projecting nose-clips, which may be set either in the same plane with the glasses, or in a plane behind that of the glasses, and inclined to them at any required angle to secure the best possible bearing upon the sides of the nose; some eyeglasses have also a provision for adjusting the clips upon the two sides, so as to fit noses of almost any shape and thickness, and of very considerable degrees of asymmetry. A cork lining to the clips possesses many advantages—in softness to the skin and in holding glasses in position. At the present time the all-metal guards (without any cork or shell lining) are being highly recommended as more sanitary, and, besides, can be more easily bent and adjusted to the nose without danger of injury to any lining. The tilting of the glasses, in cases of exceptional prominence of the forehead, can, in a great measure, be obviated by giving to the connecting spring a decided forward slant, as in the Grecian spring.

All that has been said regarding the position of the glasses when mounted in spectacle frames applies equally to eyeglasses, and it is often possible, by taking sufficient pains with modern patents of eyeglasses, to fit up a *pince-nez* which shall prove a tolerable substitute for a pair of spectacles.

For mounting cylindrical and prismatic lenses, eyeglass frames are especially unsuitable, by reason of the difficulty which is apt to be experienced in keeping them straight before the two eyes, although even this difficulty is, to a great extent, obviated by the recent patent forms of guards. The especial convenience of eyeglasses lies in the fact that they are easily put on and off. They are not so well suited for reading except for a few minutes at a time, nor for continuous wearing in distant vision. In many cases of asthenopia, and in progressive myopia especially, the wearing of eyeglasses should be prohibited.

In spite of everything the optometrist can say against the wearing of eyeglasses, his patient, in the large majority of cases, will insist on having them and will often absolutely refuse to wear spectacles. Fortunately, the objections that formerly applied to eyeglasses have been largely overcome in the many excellent devices that have been recently put upon the market, and especially those forms with a rigid bridge or spring.

EXAMINATION OF EYES.

The different methods used in testing eyes for the correction of the several refractive and accommodative defects, whether simple or complicated, will be fully described under their proper heads. Suffice it to say at this time that the points to be investigated in all cases are:

1. The state of the refraction.
2. The acuteness of vision.
3. The state of the accommodation.

Only after these three determinations have been made with at least approximate accuracy, can the selection of glasses for any particular kind of work be made intelligently. In the present state of diffusion of knowledge in the domain of physiological optics, these tests can be safely intrusted only to the ophthalmic specialist, such as have given the subject special study and taken a course with an optical college; spectacle dealers and jewelers, and even the general practicing physician, being alike incompetent, as a rule, to decide any but the simplest questions.

A person who has arrived at the age of forty-five years without having experienced any trouble in the continuous use of his eyes in near and distant work may not be likely to commit any great error in buying weak convex glasses when he becomes conscious that he is suffering from the disabilities of presbyopia; but even in such a case an examination of the eyes by a competent observer may bring to light some measure of astigmatism which it may be well worth while to correct, or possibly some pathological condition which it may be of vital consequence to detect in its incipiency. The indiscriminate selling of concave spectacles and eyeglasses to young myopes, or to young people hastily assumed to be myopic, is a most reprehensible practice, although it is, unfortunately, an almost universal one.

ABERRATION.

Optometrists frequently see and hear the terms "chromatic and spherical aberration," and it is important that they should have a clear understanding of what is meant by them. An extended intercourse with opticians has shown that a majority of them do not have the slightest idea of what is meant by these terms, while others have a vague and incorrect idea about them. The answers given to these questions are oftentimes most laughable—so very far from the real meaning are they.

Aberration of light is a peculiar phenomenon, which causes an alteration in the apparent position of a star from its true place in the heavens; this deviation being but slight in the course of a year. It is due to the fact that the observer is carried along by the motion of the earth in its orbit, while the light is traveling from the star to the earth, and the velocity of the earth's motion is a measurable quantity in relation to the velocity of light. The aberration of light is, therefore, due to the combined effect of the transmission of light and of the earth's motion. The effect of this combination of motions may be best explained by a familiar illustration.

Suppose the raindrops were falling (in a perfect calm) perpendicular to the earth's surface, and the observer were standing on a platform-car, on a railroad track, and rapidly moving forward and backward; the drops would strike him at an angle deviating from the perpendicular in proportion to the swiftness of his motion. The direction of this deviation would, in either case, be toward the side to which he is moving; and this is just the case with the light coming to us from the heavenly bodies. This becomes evident when we compare the direction of the raindrops with that of the light and the motion of the car with that of the earth in its yearly orbit. It is just as evident that if the direction in which light reaches us be changed, the position of the body from which the light proceeds must be changed also.

Lenses which form perfect images are very difficult of construction, and there are two main imperfections to be corrected—chromatic and spherical aberration.

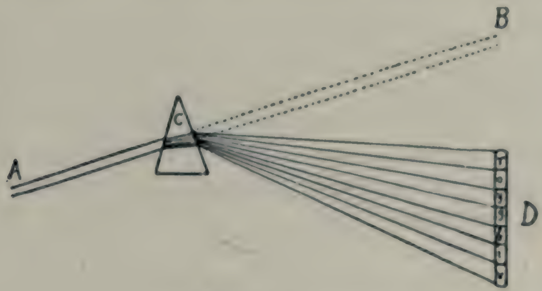
CHROMATIC ABERRATION.

In studying the first of these conditions, we find that in the image formed by a simple, ordinary lens all the outlines of figures are found to be slightly edged with rainbow hues. If we look through such a lens at an object, the outlines of the object will be similarly edged with colors, especially if the object lie near the margin of the lens. The explanation of this condition is as follows:

Ordinary sunlight, as every one knows, consists of a number of colors mixed together, the mixture producing the impression of *white.* If a beam of sunlight be made to pass through a glass prism, the beam is not only bent, but the different colors of which the beam is composed are unequally bent, so that they are separated and spread out over a considerable space, this colored space being called the spectrum, and the different colors into which the white light is separated are, in their regular order, red, orange, yellow, green, blue, indigo and violet.

In the figure below the ray of light *A B* is bent by the prism so as to become *A C D;* this is known as *refraction* of a ray of light. But each of these different colors is refracted in a different degree, by the lens, and they are incapable of being united by it in any one single focus; red is bent the least and violet the most, the other colors lying between these extremes, thus being spread out over a considerable colored space. This unequal refraction is known as *dispersion.*

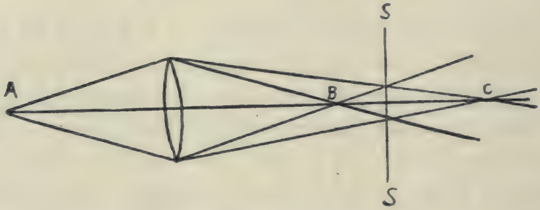
If we look through a prism at objects, we will find that the outlines of the objects will be edged with exactly similar colors.



Spectrum.

Now, all refraction is accompanied by dispersion; and, therefore, a simple, uncorrected lens always disperses, especially on the edges, where the refraction is greatest; and consequently the images made by such a lens will also be edged with colors. As the convex lenses used in telescopes, microscopes and other optical instruments refract the light to focal points, this dispersion causes an infinite number of foci.

In the figure on page 136 the light from a radiant point *A* is refracted by the lens, and, being white light, is also dispersed; the violet rays, being bent the most, reach a focus at *B*, while the red rays, being refracted the least, come to a focus at *C*, and the other colors of the spectrum at intermediate points. There is, therefore, no point where all the rays from the light *A* come to a focus; that is, there is no common focal point for *A*. The best place for the receiving screen would be $S\ S$; but even here there is no perfect focus. Evidently, therefore, the conditions of a



Chromatic Aberration.

perfect image are not fulfilled. The question at once occurs: "Can this defect be corrected?"—and the answer is, that it is corrected in every good lens.

CORRECTION OF CHROMATIC ABERRATION.

In order to understand how this is done, it must be remembered that concave and convex lenses antagonize each other, and if of equal refractive power, they neutralize each other. Therefore, a combination of a double convex and a double concave lens, if of same material and of equal curvature, will produce no refraction, because the refraction produced in one direction by the convex lens is completely destroyed by the refraction in the opposite direction of the concave lens. Such a combination will, therefore, make no image. In order that a combination of a convex and a concave glass should produce an image, it is necessary that the convexity should predominate over the concavity; this is the first point to be remembered.

It might seem, on first thought, that the amount of dispersion would be proportional to the amount of refraction, but experiments have proven that diverse refracting substances differ considerably in this respect, and hence we have the second point to be remembered, and that is, that dispersion is not always in proportion to refraction. Some substances have a higher refractive power and a comparatively low dispersive power, and *vice versa*. This is the case with different kinds of glass. Their dispersing and refracting properties are determined by passing a ray of light through solid prisms of different material, or liquid prisms enclosed between glass plates. The refractive power is then measured by the amount of deviation of the ray, and the dispersive power by the length of the colored spectrum produced. So it has been found that if the relative amounts of refraction of water, crown glass, flint glass, and oil of cassia are expressed by the numbers 133, 152, 162 and 159, the amounts of dispersion or the lengths of their spectra are in ratio of 145, 203, 433 and 1080. If the angle of a prism is increased, the refracting and dispersing power both increase in the same ratio; and it is evident that two prisms of different material may be made at such angles that they produce the same length of spectrum or possess the same dispersion, but that then their refracting powers will not be the same.

ACHROMATIC LENSES.

Now, suppose we select a glass with excess of refractive over dispersive power for our convex lens, and one with excess of dispersive over refractive power for our plano-concave lens, and cement these together as a compound lens. It is evident that they may be so related that the plano-concave lens shall entirely correct the dispersion of the convex lens without neutralizing its refraction, and therefore the combination will be a refractive but not a dispersive lens, and therefore will produce a pure white spot without colored edges. Such a compound lens is called *achromatic*.

This is the principle on which art makes achromatic lenses, and all our modern telescopes, microscopes, photographic and good optical instruments have their lenses thus corrected.

It is an interesting historic fact that the hint for the correction of chromatism by combination of lenses was taken from the structure of the eye by Enler, and afterward carried out successfully by Dollond. That the chromatism of the eye is substantially corrected is shown by the complete absence of colored edges of strongly illuminated objects and the sharp definition of objects seen by good eyes.

A convex lens of crown glass brings the rays together to a number of differently colored foci, of which the red rays will be farthest from the lens. A concave lens will throw the red rays nearest the axis; and if this concave lens is made of flint glass (a material having a slightly greater refracting power and a much greater dispersive power), and ground to such a curve as completely to neutralize the dispersion or coloring of the first lens, while it affects its refraction only so far as to lengthen its focal distance, the combination will bring the rays to a focus without separating the luminous rays into their colored constituents. Such a lens is said to be corrected for chromatic aberration. Sometimes the concave correcting lens of flint glass does not quite accomplish the purpose, and the combination is said to be under-corrected; but sometimes the opposite is the case, when the combination is said to be over-corrected.

HOW NATURE CORRECTS CHROMATIC ABERRATION.

The lenses of the eye are also apparently corrected in a similar manner. The eye (or rather the refractive media of the eye) consists of three lenses—the aqueous, the crystalline and the vitreous. These have curvatures of different kinds and degrees—the aqueous is convex in front and concave behind; the crystalline is bi-convex, and the vitreous is concave in front. As the convex outer surface of the vitreous cannot be regarded as a refracting surface, since it is in direct contact with the screen to be impressed, it may be considered as a plano-concave lens. The refractive powers of the material of these are also different—that of the crystalline being greatest and the aqueous least. Their dispersive powers have not been determined, but they probably differ in this respect also. Thus, then, we have here also a combination of different lenses, of different curvatures, and different refractive and probably different dispersive power, and all for the same purpose, and that is the correction of chromatism. Then, too, we are not conscious of this defect for another reason, and that is because the eye is adjusted for the middle and brightest portion of the spectrum, *viz.,* yellow and green to blue, while the red and violet rays form circles of diffusion around the image, which blend, and thereby diminish in distinctness of color; being, moreover, much less bright than the sharply-defined image which they surround.

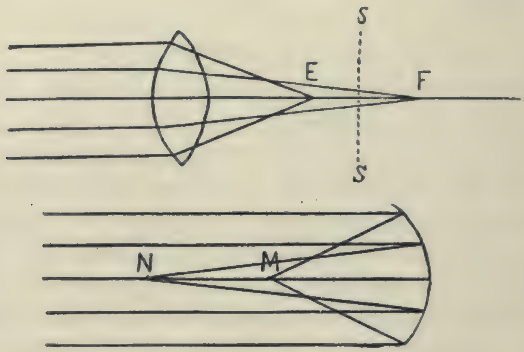
But we can see these colored circles of diffusion quite distinctly on looking at some bright object, while covering one-half of the pupillary aperture with an opaque screen, for by thus cutting off one-half of the pencil of light we prevent the blending of the color-rings, and the object shows, then, a blue edge on one side and a yellow margin on the other. The chromatic aberration is also quite noticeable on observing a luminous point through a cobalt glass, which absorbs the middle part of the spectrum, whereupon we see either a red point surrounded by a blue halo, or a red margin around a blue point of light, according to the refractive state of the eye. So that, by close observation and refined methods, we must admit that it can be shown that the chromatism of the eye is not perfectly corrected after all; it can be observed in the extreme colors, red and violet; but its degree is so small as not to interfere at all with the accuracy and clearness of vision.

SPHERICAL ABERRATION.

We come now to the consideration of another defect, much more difficult of correction, and which is known as *spherical aberration*, or simply *aberration*, in contradistinction to chromatic aberration, which is known simply as *chromatism*. Spherical aberration arises from the nature of the curve used in making lenses and reflectors. Geometry proves that parallel rays can only be refracted and reflected to a single focus by a parabolic curve; but the form of lenses and reflectors most easily made has a spherical curvature; that is, they are ground as part of a sphere, which differs from a parabola in the fact that in the latter the amount of curvature increases toward the center or axis. The consequence is that a section of a sphere, or an ordinary spherical lens, not having curvature enough toward this point, has an infinite number of foci at different distances; that is, there is a difference in the refractive power of different portions of the same lens, the marginal portions of the lens having an excess of refractive power as compared with the central portions, which excess of refraction increases with the distance from the center; therefore the focal point for marginal rays is not the same as for the central rays—that formed by the portions of the lens nearest the axis will be the farthest away, while that formed by the portions of the lens closest to the circumference will be the nearest.

The two figures on page 140 represent the case of this aberration by refraction and by reflection. In the first figure, illustrating the case of refraction, the marginal rays, or those passing near the circumference of the lens, are quickly united in a focus, as at *E*, while the central rays or those passing near the axis of the lens, are not brought to a focus so soon, it being farther away, as at *F*. The best place for the receiving screen would be between these two points, as at S S, but even there the image would not be sharp and clear.

In the second figure, illustrating the case of reflection, the curved mirror or reflector reflects the rays falling on it near the circumference to a near point, as at M, while the rays falling on the mirror near the center will be reflected to a farther point, as at N. In such lenses there is no common focal point for all the rays.



Spherical Aberration.

and, therefore, the conditions of a perfect image are not fulfilled —the image is more or less blurred. This defect should be corrected—and it is corrected—in the best lenses. When the aperture of the lens or mirror is small, these differences are practically inappreciable; but when the aperture must be large, as is the case with astronomical telescopes, peculiar arrangements are contrived, so that in making the lenses or reflectors a curve is obtained as nearly as possible of the parabolic form.

CORRECTION OF ABERRATION.

Spherical aberration may be greatly decreased by the use of diaphragms, which cut off all but the central rays, but in this case we obtain distinctness at the expense of brightness, and this can only be done when the light is very intensely bright. Again, spherical aberration may be reduced by using several very flat lenses instead of one thick lens, which is the plan used in many instruments. But complete correction can only be made by increasing the refraction of the central portions of the lens, and this may be accomplished in two ways, viz., either by increasing its density, or by increasing the curvature of this part, and, therefore, its refractive power. It is by this last method that art makes the correction. By mathematical calculation it is found that the curve must be that of an ellipse. A lens, to make a perfect image, must not be a segment of a sphere, but of the end of an ellipsoid of revolution about its major axis. It is justly considered one of the greatest triumphs of science to have calculated the curve, and of art to have carried out successfully the suggestion of science.

Art has not been able to achieve success by the first-mentioned method. It has not been found possible to so graduate the increasing density of glass from the surface to the center of a lens so as to correct the aberration; but it is apparently by this first method, or, perhaps, by a combination of both, that nature is enabled to correct the spherical aberration that would otherwise exist in the eye. The crystalline lens increases in density and refractive power from surface to center, so that it may be regarded as consisting of ideal concentric layers, increasing in density and curvature until the central nucleus is a very dense and highly refractive spherule.

The surface of the cornea has the form of an ellipsoid of revolution about its major axis, and, therefore, doubtless contributes to the same effect. In looking at very near objects, the contraction of the pupil also tends in the same direction by cutting off the marginal rays. But, however the result is accomplished, whether by one or both methods, it is certain that in good eyes it is completely achieved, because the clearness of vision is wholly conditioned on the sharpness of the retinal image.

It is probable that the peculiar structure of the crystalline lens has also another important use in the lower animals, if not in man. It has been shown that in a homogeneous lens, while the rays from radiants near the middle of the field of view (that is, directly in front) are brought to a perfect focus, the rays from radiants situated near the margins of the field of view (that is, of very oblique pencils) are not brought to a focus. Therefore the picture formed by such a lens is distinct in the central parts, but very indistinct on the margins. Now it has been shown that this defect of a homogeneous lens is entirely corrected in the crystalline lens by its peculiar structure; therefore, this peculiar structure confers on the eye the capacity of seeing distinctly over a wide field without changing the position of the point of sight. This capacity has been called *periscopism.*

ADVANTAGES OF PERISCOPIC LENSES.

The ideal way to correct an optical defect would be to place the correcting lens into the eye and to make it an integral part of the eye. This being impossible, it is placed in front of the eye, as the only other thing that can be done; but, unfortunately, it cannot move with the eye, and hence, to get the full benefit of the lens and to avoid the disturbing effect of looking through the edges of the glass in looking around, the head must be turned rather than the eye. With periscopic lenses there is, perhaps, a freer range of the eye behind the glass, and hence periscopic lenses are considered preferable to double, except in the strong numbers; but not universally, however. There seems to be a growing sentiment in favor of double lenses, and opticians are beginning latterly to look with more favor on them for general use. They sometimes order one and sometimes the other, according to special cases.

PERISCOPIC AND DOUBLE LENSES.

There is an interesting fact in connection with periscopic and double lenses that should be known to every optometrist, and that is that the eye may become so much accustomed to wearing one kind as to be unable to wear the other. Many cases like the following are known: A person is wearing glasses that seem in every way suitable; he goes to the optician to buy a new pair exactly like the old ones, either because the old ones are worn out, or because he wants to have an additional pair. He at once finds that the new ones are uncomfortable, and is soon unable to wear them at all. He goes back to the optician and tells him the glasses are not right and he cannot wear them. The optometrist measures the focus and finds it the same as the old glasses, and assures his customer that the new glasses are all right, are just like the old ones, and advises a perseverance in their use. The customer tries the new glasses again, with the same unpleasant result, until he becomes disgusted with himself and full of blame for the optometrist. Now the secret of it all is that the customer had, perhaps, been accustomed to wearing periscopic lenses, while the new ones given him were double; or, perhaps, the old ones were double and the new ones periscopic.

HOW TO MEASURE LENSES.

It is often necessary for the optician to determine exactly the strength or number of a lens that comes into his hands, and every optician should be able to do this quickly and accurately. The first thing to be determined is whether it is a convex or a concave lens, and the second point for determination is as to whether it is a simple or a compound lens.

In ascertaining the first point, the lens is held up to the light and the observer looks through it at the window-sash or any stationary object; the lens is then moved to and fro before the eye while the sight is fixed upon the object, and if the object looked at appears to move in the *same direction* with the lens, it is a *concave lens;* while if the object appears to move in an *opposite direction* to the lens, it is a *convex lens.* An experienced observer, after a little practice, can at the same time give an approximate guess as to the strength of the lens by noticing the rapidity with which the object appears to move in one direction or the other; the stronger the lens the more the apparent motion, while the weaker the lens the less will be the apparent motion, until the lens becomes so weak as to be a plane lens, when there is no apparent motion at all.

TO MEASURE FOCAL DISTANCE OF A LENS.

The strength of a convex lens can be exactly ascertained by directly measuring its focal distance. In following this method the lens is held in front of a window in such a way that the rays from outside objects will pass directly through it, and images of such outside objects will be formed upon a screen or paper placed back of the lens. Then either the screen or the lens is moved to and fro, nearer to or farther from each other, in order to ascertain exactly the distance apart they are when the images of the outside objects formed on the screen are the clearest and most distinct. This distance (that is, the distance of the lens from the screen) is the distance desired, and expresses the strength or number of the lens in inches, if an ordinary yard-stick or rule be used; while if the optometrist is accustomed to use the metric system, he can readily convert this inch-number into dioptres, according to the rule which will be given in the next chapter.

In order to ascertain the strength of a concave lens, according to the same method, we combine with it a stronger convex lens, and then measure the focal distance of the lens resulting from the union of the two, which, when found, we subtract from the strength of the original convex lens, and the remainder is the strength of the concave lens desired. For instance, suppose the original convex lens was a + 5 D. lens, and after the concave lens was placed in union with it the resulting convex lens was + 2 D., then the strength of the concave lens would be — 3 D., as follows: 5 D. — 2 D. = 3 D. Instruments have been constructed on these principles for the purpose of measuring lenses, by means of which it is possible to ascertain the focal length of any lens in a few seconds, by reading it directly from the scale attached to the instrument.

Neutralization.—Measuring lenses by neutralizing them is, however, the most commonly used method and the most convenient. This method depends on the finding of another lens that will exactly neutralize or nullify the lens desired to be measured; that is, make it of none effect, or as a plane glass.

As soon as a lens comes into the experienced optician's hands, his practiced eye tells him in an instant if it is convex or concave, according to the method already described. If it be convex, he takes from his trial-case a concave lens of such strength as he thinks will nearly neutralize it, and placing the two together he tries the effect of the combination on the opposite window-sash. If there is not an exact neutralization, it can be seen at once which is the stronger. If the combination causes the sash to move in the opposite direction, you know that the concave lens you have taken from your set of test-lenses is not strong enough to exactly neutralize the convex, and you take another and a stronger one, until you do find one that is just strong enough to neutralize the convex lens and the combination acts as a piece of plane glass. If, on the other hand, the combination causes the sash, when looked at through the lens, to move in the same direction, you know that the concave lens more than neutralizes the convex lens you are testing, and then you must take another and a weaker one, until you find one that is just weak enough (or strong enough) to exactly neutralize the lens that is being tested, when the combination will act as a piece of plane glass, and there will be no movement of the window-sash with movement of the combined lenses.

To illustrate this subject of neutralization, when you take up a new lens you see at once that it is convex, and you judge by the rapidity of the movement of the window-sash that it is about + 3 D. You take up a — 3 D. lens from your test-case, and, placing the two lenses together, and moving them while looking at the window-sash, you expect to find perfect neutralization, instead of which you find a slight movement *against* the lenses. You know from this that the convex lens is not yet fully neutralized, and as the movement is but slight, it becomes evident that the difference cannot be very great. You then try a — 4 D. lens, and now the

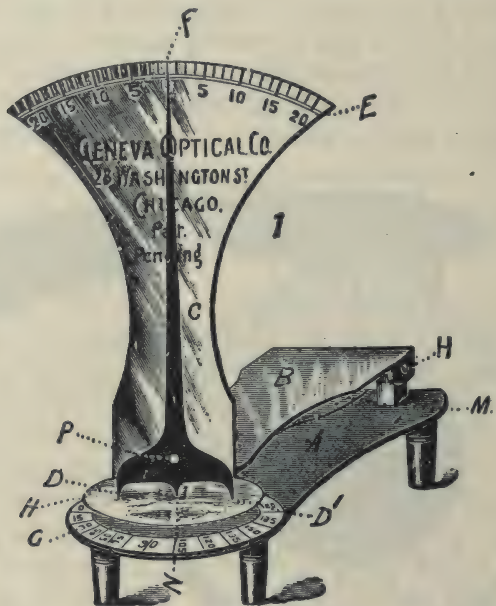
movement is *with* the lenses, and you know that the convex lens is more than neutralized. Having thus found that — 3 D. is not strong enough, and that — 4 D. is too strong, you then try — 3.50 D., and this time you find that there is not the slightest movement when looking through the lenses in motion, and therefore you know that there is a complete and perfect neutralization; and as you know that the strength of the concave lens is — 3.50, it follows, as a consequence, that the strength of the convex lens must be + 3.50.

LENS-MEASURE.

The illustration, which is full size, gives a very good idea of this useful little instrument, which is to be employed in accordance with the directions on the following page.

DIRECTIONS.

There are three points (seen at top of the instrument), the two outer ones being fixed and the central one movable. The lens to be measured is pressed firmly upon these three points, thus



causing a sinking of the central one, which acts on the index finger rotating it until it points to a certain number on the scale, which will indicate the refraction in dioptres of this surface of the lens. If the index points to the left of *O*, the lens is convex; if to the right of *O*, it is concave.

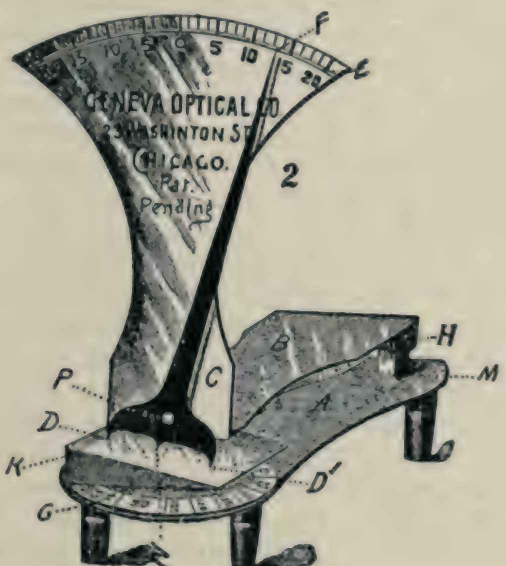
Then turn the lens and measure the other surface. If both surfaces are convex, or both concave, the numbers are added together to determine the refractive power of the lens. For example, if one surface is + .75 D. and the other surface + 1.25 D., the lens is a + 2. D. If one surface is — 1.25 D. and the other surface — 1.50 D., the lens is a — 2.75 D. If one surface is convex and the other concave (as in the case of a periscopic lens), one is to be subtracted from the other for example, if one surface is + 2.25 and the other surface — 1.25 D., the lens is a periscopic convex of 1. D.

If the lens is rotated and the index points to the same number in all its meridians, the lens is proven to be spherical. If, however, there is a variation in the pointing of the index, it cannot be a spherical lens, and it is presumed to be a cylinder. In order to determine this we rotate the lens until the pointer stops at *O*, which, being the meridian of no refraction, is the axis of the cylinder; then rotate the lens at right angles or to the place where the pointer swings farthest from *O*, when the strength of the cylinder can be read off.

In compound lenses, each surface can be measured as above, and the determination of spherical and cylindrical quickly made. When a plane lens is measured the index points to *O*. The inside large figures are dioptric numbers, and the outside small figures inch numbers.

PRISM MEASURE.—TO CENTER LENSES.

The lens to be centered is placed upon the front part of the bed-plate *A*, resting upon the lower points; the upper plate *B* is



then pressed down until the points of the index finger touch the lens, and if the lens is of the same thickness at each point (that is, at *D* and *D'*), the index will point to *O* on the scale, and the middle point (N) will be exactly over the center of the lens. (See cut on page 146.)

TO MEASURE PRISMS.

In order to determine the strength of a prism, the lens to be measured is placed in the same position as above, when the difference in the thickness of the lens at the point D and D' will cause the index finger to move along the degree circle, where the strength of the prism can be quickly read off.

TESTING A LENS FOR FLAWS.

Noticeable cracks, bubbles, specks, or other flaws in a lens are usually discoverable on a casual examination, and without the necessity of making use of any special method of examination; but they can be the more easily detected by viewing the lens with a bright light shining upon it from one side, and especially if the lens be held before a dark background, as in a room that is lighted by a single lamp or gas-burner. Reflected light from a window or lamp may be made use of to discover irregularities of the surface, by holding the lens in such positions that there may be obtained, in turn, a reflection from every portion of the surface of the lens to be examined. In this manner of examination, any interference or marring of the perfect uniform reflection that ought to be obtained can be readily detected, and the lens set aside or accepted, as the case may be.

Differences in the refractive power of certain portions of the same lens can be detected while making the attempt to neutralize the lens, by noticing whether there is imperfect neutralization in any portion of the lens. You expect to find neutralization equally perfect in all portions of the lens, and any imperfection in this respect in any portion of the lens can thus be discovered.

In this connection it should be remembered that the double lenses of the test-cases do not always allow accurate neutralization, and this imperfect neutralization is the more noticeable with the stronger numbers, with which it is possible to neutralize only the center of the lens. Plano-convex or concave lenses are not so open to this objection, but can be more accurately neutralized than double lenses.

CHAPTER VI.

NUMBERING OF LENSES.

The handling and prescribing of lenses being the optometrist's chief work, it is just as necessary for him to have a clear understanding of the manner of their construction and measurement as it is of their proper adjustment. Unfortunately, just now is a transition period in their nomenclature, rendering this subject of the numbering of lenses a matter of more than ordinary difficulty, for it requires a knowledge of both systems of numbering lenses to be able to intelligently understand the current works on the subject of optics.

About thirty years ago the present system of measurement of lenses in inches was practically introduced. Previous to that time, and before the principles which should govern the adjustment of spectacles had been investigated with scientific accuracy, and when people expected opticians and jewelers to prescribe spectacles as well as to make and sell them, there was no uniform system of numbering lenses, but those in common use were distinguished by arbitrary names or numbers. A manufacturer might make twenty grades of lenses, of no definite and fixed relation one to the other, and he would number them one to twenty as a matter of convenience. Another manufacturer might make only twelve grades of lenses, and number them from one to twelve, although they might embrace the same range as the one to twenty lenses. Every manufacturer would have his own system of numbering, and hence these numbers really meant nothing and conveyed nothing definite to the optician's mind, because the number ten of one manufacturer might be the equivalent of number eight of another, or the number twelve of a third manufacturer. Sometimes the glasses, especially in the lower powers of convex lenses, were called by arbitrary names expressive of their supposed or fancied properties, as "preservers," "clearers," and such like rubbish. All this was a source of endless confusion, and to overcome this muddled state of affairs, it gradually came to be understood that the number of the lens should indicate its focal length in inches.

This period of definite inch nomenclature commenced about

1860, and people began then to think of their spectacles in inches. Under this system, when a man would come to the optician and say, "I have been wearing number ten," the optician would understand that glasses of ten inches focal length were meant, and not some indefinite number ten of some manufacturer of the pre-scientific period.

But although this was a great improvement over the old system of numbering, then a new source of error and confusion arose from the fact that the inches of different countries were not exact equivalents; the Parisian inch is the equivalent of 27.07 millimeters; the English inch of 25.30 millimeters; the Austrian inch of 26.34 millimeters, and the Prussian inch of 26.15 millimeters.

Now the refracting power of a lens depends also on the index of refraction of the glass, varying with the kind of which it is composed. The index of refraction of the glass of which lenses are constructed varies all the way from 1.526 to 1.534, and hence there are sources of error in all calculations; for even though the country is known where the lenses are made, and, of course, presumably on the standard of that country, the exact refracting power can never be told unless the index of refraction of the glass is known as well. In order to simplify the latter, a common index of refraction of 1.5 was accepted; but even with that wrong basis, only part of the trouble was removed, so that, as a compromise, it became generally accepted that the number of a lens indicated both the focal distance and the refracting power. Thus a lens numbered nine had a focal distance of nine inches and a refracting power of one-ninth. But it was really known all the time that it had not, and it in no way made an intelligent person feel that he had solved a practical matter by trying to deceive himself with what he knew was not right. In other words, a sensible system of rotation would indicate either the power of refraction or the focal distance of a lens. This old system did neither, and by making the unit too strong necessitated the constant use of fractions in all calculations. Practically we have much more to do with the refracting power of a lens than with the focal distance. The refracting power is always the inverse of the focal distance. The numbers of the old system give the focal distance of the lens in inches, the unit being a lens of one inch with the refracting power of 1/1. There is seldom any need of this lens in practice, and it is not put into the ordinary trial-cases.

According to the inch system of numbering spectacle lenses, a glass of one inch focus is taken as the standard; this unit being the strongest lens, all other lenses are weaker and must necessarily be expressed in fractions. There might be stronger lenses than this unit—as, for instance, a lens whose focal distance was only one-half inch, and whose refracting power would be double that of the unit—but such strong lenses are never needed or used for spectacle purposes, and hence we regard the unit or one-inch lens as the strongest of the series. A lens having a focal distance of two inches—that is, twice the length of the focal distance of the unit lens—would possess one-half its strength, and would be expressed by the fraction ½. A lens having a focal distance of ten inches—that is, ten times the length of the focal distance of the unit lens—would possess only one-tenth its refracting power, and would be expressed by the fraction 1/10. A lens having a focal distance of seventy-two inches—that is, seventy-two times the length of the focal distance of the unit lens—would possess only one-seventy-second of its refracting power, and would be expressed by the fraction 1/72. Thus it will be seen that all the various lenses weaker in proportion are represented by corresponding fractions, and the denominator of the fraction always expresses the focal distance and refracting power.

This is the system, then, that has been in common use until of late years, and is still adhered to by the older opticians of the present day; and although a fairly satisfactory system, it is open to many objections, a few of which I will mention.

The chief difficulty occurred when it was desired to combine lenses together, as the addition had to be made entirely in fractions. When a seventy-two-inch lens and a twenty-inch lens were to be combined, we had to deal with their refracting powers, and not their focal distances; in the case just mentioned, the focal distances would be seventy-two inches and twenty inches, while the refracting powers would be 1/72 and 1/20; and as it is the latter only that are to be considered, it is evident that the addition must be made in fractions. In this case we have $1/72+1/20$ as the problem; and while every schoolboy knows how it can be done, it is, more or less, a tedious process, and takes a little time, involves some figuring, and scarcely can be done in the head. We reduce them to a common denominator, and we have $1/72=20/1440$ and and $1/20=72/1440$. Then $20/1440+72/1440=92/1440$, or about

1/15 2-3, which we call 1/16. Who will not say that the necessity that constantly arises in the everyday experience of optometrists for the frequent addition and subtraction of fractions, like the above, in the combination of ordinary lenses, is a powerful objection to the inch system, as it is a most troublesome, difficult and tedious process, and one that is fraught with many liabilities of error and mistake?

Another objection that may be urged against the inch system is that the intervals between the lenses are not regular nor uniform; for instance, the difference between an eight-inch and a nine-inch lens—that is, between a 1/8 and a 1/9 lens—is much greater than between a twelve-inch lens and a thirteen-inch lens—that is, between a 1/12 and a 1/13. The interval between any two lenses of the inch system is never the same as between two other lenses of the same system, the difference between a 1/11 and a 1/10 lens is not the same as between a 1/10 and a 1/9, and, as can be readily seen, the lower down in the scale you go, and the stronger the numbers become, the greater the difference between the adjoining numbers. This lack of uniformity in the intervals between the lenses of the inch system constitutes an objection to that system which is scarcely less formidable than the first-mentioned one of the difficulty of combining fractions.

The last objection, and which I will merely mention, is that the standard or unit of the inch system (one inch) is so strong that it is seldom, if ever, used.

THE DIOPTRIC SYSTEM.

To overcome and obviate the difficulties of and objections to the inch system, many plans and systems have been offered by different oculists and introduced at their various conventions and meetings. This resulted in the proposal, at the International Congress of Ophthalmology, in 1867, of a new system of numbering all lenses according to their refractive power; this was followed by the decision of the Ophthalmological Congress, in 1872, to adopt a metrical scale of measurement, which new or metric system was finally adopted by the Ophthalmological Society, which convened at Heidelburg in 1875.

This system selects for its unit a lens with a focal distance of one meter (instead of one inch, as in the old system), and which is called a *dioptre,* it being also written dioptry and dioptric, and is represented by the abbreviation D. In this system, then, a weak number instead of a strong one (as in the inch system) is used for the unit, and, as the majority of the lenses used are stronger than this, their refracting power can be represented in whole numbers. A lens of twice the strength is a two-dioptre (or 2 D.), and it has a focal distance of one-half meter. A lens of four times the strength is a four-dioptre (or 4 D.), and has a focal distance of one-quarter of a meter. It will be seen that in all these lenses the focal distance is always some fraction of a meter, while the number of the lens expresses its refracting power, and not its focal length as in the old system. This gives us a series of lenses with an equidistant interval of one dioptre, and the numbers 1 D. to 20 D. indicate the uniformly increasing power of the glasses.

Unfortunately, for the practical uses of the optometrist there is need of lenses weaker than one dioptre and at intervals between the dioptres, so that this system does not, after all, remove the need of fractions, but it substitutes for the vulgar fractions the so-called decimal fractions, which do not add anything to the difficulty of combining such lenses. This furnishes us with three intermediate lenses between the dioptres and the same number of lenses weaker than a dioptre, viz., .25 D., .50 D. and .75 D., or one-quarter of a dioptre, one-half a dioptre and three-quarters of a dioptre as expressive of their refracting power, while their focal distances would be respectively four meters, two meters and one and one-third meters.

Of late years there has been a tendency to make a still finer sub-division of lenses by the introduction of a .12½ D. lens, which would furnish us four more lenses between the dioptres, and the same number of additional lenses weaker than the dioptre, as follows: .12½ D., .25 D., .37½ D., .50 D., .62½ D., .75 D., .87½ D., 1 D., 1.12½ D., 1.25 D., 1.37½ D., 1.50 D., 1.62½ D., 1.75 D., 1.87½ D., 2 D., and so on. The value of these fractions of ½ is so trifling that they can be discarded without detriment, and the series would then read, .12, .25, .37, .50, .62, .75, 87 and 1 D.

This gives the optometrist a series of lenses that may fairly be called complete, and with an equidistant interval between each one.

The two chief objections urged against the inch system—that is, the difficulty of combining the vulgar fractions of which they are composed, and the irregular intervals between the lenses—are entirely removed in the dioptric system, as the addition or subtraction of dioptres is easy and simple to the extreme, while the interpolation of the decimal fractions adds nothing to the difficulty of such addition or subtraction, it being done as easily as the whole dioptres; in fact, it is the same as the addition or subtraction of dollars and cents.

METRIC AND INCH SYSTEMS COMPARED.

The following table explains itself, and should not only be carefully studied, but should be kept convenient for ready reference:

Dioptric System	English inch 1 meter = about 40 inches	French inch 1 meter = about 36 inches	Dioptric System	English inch 1 meter = about 40 inches	French inch 1 meter = about 36 inches
0.12	320	288	5.	8	7
0.25	160	144	5.50	7	6½
0.37	108	99	6.	6½	6
0.50	80	72	6.50	6	5½
0.62	64	58	7.	5½	5
0.75	53	48	7.50	5⅓	4⅘
0.87	46	41	8.	5	4½
1.	40	36	8.50	4⅔	4¼
1.25	32	29	9.	4½	4
1.50	26	24	9.50	4⅕	3¾
1.75	22	20	10.	4	3⅗
2.	20	18	11.	3½	3¼
2.25	18	16	12.	3¼	3
2.50	16	14	13.	3	2$\frac{10}{13}$
2.75	14	13	14.	2¾	2$\frac{4}{7}$
3.	13	12	15.	2⅔	2⅖
3.25	12	11	16.	2½	2¼
3.50	11	10	17.	2⅓	2⅛
3.75	10⅔	9½	18.	2¼	2
4.	10	9	19.	2$\frac{1}{9}$	1$\frac{17}{19}$
4.50	9	8	20.	2	1⅘

The first column gives the number of the lens ground according to the new dioptric or metric system, and the second and third columns its equivalent in English and French inches respectively. The table shows the focal distance of the lenses in general use, and affords an understanding of the relative value of the old and new systems. The meter is taken as the standard, and is considered equal to forty English inches or thirty-six French inches; these are not the exact figures, the equivalent in English inches being a fraction over thirty-nine inches, and in French inches a fraction over thirty-six inches, but the whole numbers of forty and thirty-six are sufficiently accurate for all practical purposes, and are universally used in making the comparisons between the two systems. The French inch may be left out of the question, as the English inch is the one we use, and hence all the calculations are made on the basis of a meter equaling forty inches.

The test-cases used by oculists and opticians were, until recently, composed of lenses ground according to the French inch system; and it can be easily seen how an error and much inconvenience might result, with corresponding discomfort to the patient's eyes, if a prescription based upon the French inch test-cases was filled by an optician whose lenses were ground according to the English inch system, and who, therefore, failed to furnish the glasses intended by the prescriber; and the difference would be all the more marked if the lenses prescribed were among the stronger numbers.

In converting inches into dioptres, or dioptres into inches, we make use of the following simple rule: To find the focal distance of a lens in inches, we divide forty by the number of the dioptres; and to find the number of the lens in dioptres, we divide forty by the number of inches.

According to the above method of calculation, the focal distance of a lens is the inverse of its refractive power. Take, for example, a lens of 4 D.; if we wish to find its equivalent in the inch system we divide it into forty, equaling ten inches; or as the focal distance of a lens is the inverse of its refractive power, then with a lens of 4 D. we have the following:

$$\frac{1\text{ m.}}{4} = \frac{100\text{ cm.}}{4} = 25\text{ cm.} = 10\text{ inches.}$$

This means that one meter, or its equivalent one hundred centimeters, divided by four equals twenty-five centimeters, which in turn equals ten inches.

In the same way we can find the number of the dioptre, which is the inverse of the focal distance. Take, for example, a lens of eight inches focal length, which is equal to twenty cm., and we then have the following:

$$\frac{1\text{ m.}}{20} = \frac{100\text{ cm.}}{20} = 5\text{ D.}$$

The simple rule to be remembered in making any and all calculations in the conversion of inches into dioptres or dioptres into inches, is in the one case to simply divide forty by the refracting power in inches (which gives the number of dioptres), and in the other case to divide forty by the number of dioptres (which gives the number of inches). This simple rule of calculation is in constant use, and if the optometrist is at all apt with figures, the calculation can usually be made mentally without any recourse to figuring with paper and pencil. After some experience with the two systems, and the constant conversion of one into the other, which their use necessitates, the optometrist soon has their equivalent values fixed in his mind, so that when he picks up a lens marked in inches, its value in dioptres at once occurs to his mind, and that without any mental effort on his part.

One of the advantages that might be mentioned of using the metrical system, is that it prevents your customer from knowing or learning the inch number of the glasses he is or should be wearing. Some persons are unkind and dishonest enough, after the optometrist has spent a great deal of time in testing their eyes, to ascertain from him the proper number of the glasses they need, and then, with some trivial excuse or with the remark that they will call again, they go around the corner to some street peddler of spectacles and ask for the number the optometrist found to be suitable for their eyes. This can be prevented by the constant use of the dioptric system of numbering; or, what is still better, in the great majority of cases, is not to let the customer know the number of the glass that is given him or that suits him. If he learns this he is independent, and in case he breaks or loses his glasses he can go to any peddler or general merchandise store and obtain the proper number of glasses; otherwise he must return to the optometrist who furnished his glasses when he needs a new pair, and thus he can be kept somewhat dependent upon the optometrist, with a bond more or less firm, as the capabilities of the optometrist will warrant. Or, if the customer makes the request to know the number of the lenses that he needs, the optometrist can truthfully reply that his lenses are not ground according to the common inch system, but according to the new French metrical system, without, of course, any mention being made to the customer that even though they are numbered on the metrical system, they might have an equivalent in the more common inch system. This sometimes satisfies the customer, and no more questions are asked. If, however, he is not satisfied with this evasive reply, and the optometrist feels he cannot refuse to give him the number, it is given according to the metrical system with the dioptric number—it may be 3 D., it may be 2 D., it may be 1 D.—and he is simply told it is 3, 2 or 1, as the case may be; and if he goes off with the intention of purchasing this number elsewhere, and asks for it from an optician who is not thoroughly posted, it would be next to impossible for him to obtain the proper glasses, and he would begin to think that the first optometrist probably understood best how to fit his eyes after all.

CHAPTER VII.

TRANSPOSITION OF LENSES.

This subject is one not only of great interest, but of much importance to the optician. In the start it should be remembered that the glass from which lenses are made varies in composition, thus producing a difference in the index of refraction of the lens. Now, the refractive power of a lens, or rather its focal length, depends upon two factors, viz., the radius of curvature on which it is ground and the index of refraction of the glass from which it is made. So that the focal length, the index of refraction and the radius of curvature are three factors that bear a constant relation to each other; hence, when any two of them are known, the third can be at once determined, the rule for which might be worded as follows: *To find the focal length of a lens we divide the radius of curvature by twice the index of refraction, less one.*

But, in order to simplify the matter and avoid unnecessary technicalities, we will consider the index of refraction as constant, and then our interest will be confined to the curvature of the surfaces of the lens.

PRISMS.

A prism is the simplest form of a refractor. Rays of light passing through a plane glass, with surfaces parallel to each other, are not turned out of their course; but, with a prism, the surfaces are inclined to each other and, hence, its optical effect is to turn the rays of light out of their course. A prism refracts light towards the base, but an object seen through the prism appears displaced toward its apex. A prism simply alters the direction of the rays of light, but does not possess the power to bring them to a focus; *hence, a prism, strictly speaking, is not a lens,* although, as a matter of convenience and for want of a more proper term, it is often referred to as such.

But if two prisms with surfaces similarly inclined are placed together base to base, as in Fig. 1, the rays of light passing through identical parts of each prism will intersect on the other side of the prism upon a line, which is an extension of the base line of the prisms.

Now, a circle may be regarded as a regular polygon, that is, a plane figure with many angles, and, consequently, with many sides, and in like manner a sphere may be regarded as a solid body bounded by an infinite number of equal plane surfaces; and as it is a poor rule that won't work both ways, the surfaces of the prisms above mentioned may be regarded as curved instead of straight, and then the result is a lens.

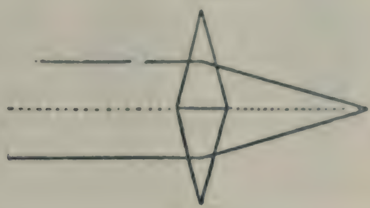


FIG. 1

Therefore, a lens may be defined as a transparent medium, with at least one curved surface, and having the power to converge or diverge rays of light, according to well-known fixed laws.

If two prisms with surfaces similarly inclined are placed together apex to apex, as in Fig. 2, the rays of light passing through identical parts of each prism will be made to diverge in equal pro-

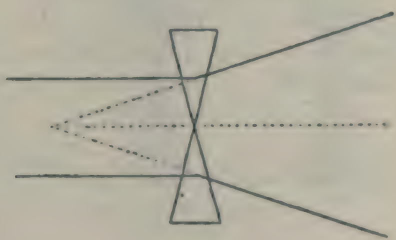


FIG. 2

portion; and if the surfaces were curved instead of straight, a concave lens would be formed, which, turning the rays of light toward the bases of the prisms as before, causes them to diverge. Such a lens has no real focus, but only a virtual or negative focus, which is located at that point where these divergent rays would meet if continued backwards. The characteristics of concave and convex lenses are similar, but of directly opposite effect.

Spherical lenses (either convex or concave) are recognized by the fact that upon rotating them around their center, there is no distortion caused of an object viewed through them at some little distance. Whereas, the convex spherical is known from the concave by the fact that the first causes a movement in the oppo-

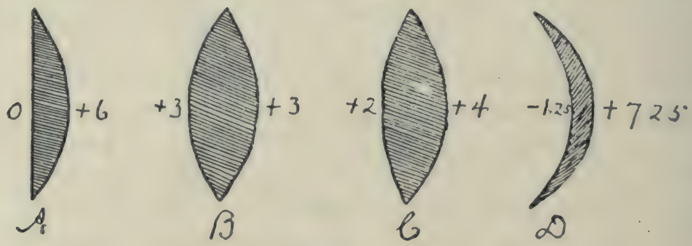


FIG. 3

A—Plano Convex. *C*—Double Convex.
B—Double Convex. *D*—Periscopic Convex.

site direction, and the latter a movement in the same direction when an object is viewed through the lens at a distance, and the lens moved from side to side with a pendulum-like motion. The strength of a spherical lens depends upon the curvature of its two surfaces, both of which must be taken into account. These two

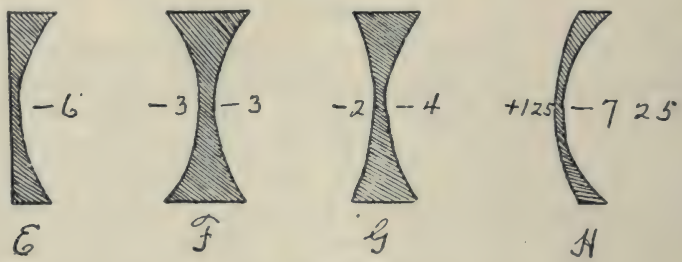


FIG. 4

E—Plano Concave. *G*—Double Concave.
F—Double Concave. *H*—Periscopic Concave.

curvatures may vary, and yet so long as the sum of the two equal the same amount, the value of the lens will be the same.

In other words, a spherical lens may be made in four different forms, all of which will possess the same refractive power, as illustrated by the curvatures of the convex lenses *A, B, C* and *D*, Fig. 3, and of the concave lenses *E, F, G* and *H*, Fig. 4.

In *A* and *E* all the curvature is on *one* surface, the other being plane.

In *B* and *F* the two surfaces are of equal curvature, thus dividing the refractive power equally between them.

In *C* and *G* both surfaces are curved, but not equally, and both contribute to the refractive power of the lens, but not to the same degree. There may be other variations of these two surfaces so long as the sum total amounts to 6 D.

In *D* and *H* one surface is convex and the other is concave, the greater always being diminished by the lesser. In *D* the convex surface predominates, but is reduced to the proper strength by the concave surface. In *H* the concave surface predominates, but is reduced to the desired strength by the convex surface. In either case the convex and concave surfaces may be increased or diminished at will so long as the subtraction of one from the other amounts to 6 D.

These lenses are called "periscopic" or "meniscus," terms which have practically the same meaning. The concave surface is always placed toward the eye, as this allows the lens to be brought nearer to it and thus increases the field of vision.

Spherical lenses may be arranged under two heads: as showing their action on parallel rays of light, we call them convergent and divergent; as showing the curvatures of their surfaces, we call them convex and concave; as indicating the character of their refractive power, we call them positive and negative, or the same idea in other words, plus and minus. As shown by the diagrams, the former have thick centers and thin edges; the latter thick edges and thin centers.

The names, forms and varieties of spherical lenses may be expressed diagrammatically as follows:

Spherical Lenses	Convergent Convex Positive Plus	Plano Convex Double Convex Periscopic Convex
	Divergent Concave Negative Minus	Plano Concave Double Concave Periscopic Concave

As previously stated, the focal length of a lens depends upon its index of refraction and its radius of curvature. For reasons there stated, the latter is the factor which will be considered in this series of articles. The larger the radius of curvature the greater will be the focal length of the lens, while the sharper the curvature the shorter the focal length.

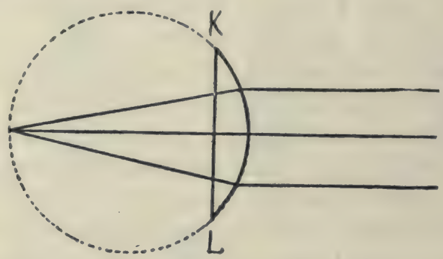


FIG. 5

Showing the focal length of a plano-convex lens to be equal to twice the length of its radius.

What is a spherical lens? The answer is, "a section of a sphere." In the diagram (Fig. 5) the dotted lines represent the outlines of a sphere, and if a section be made from *K* to *L*, the black outline will be recognized as a representation of a plano-convex spherical lens. Rays of light passing through this lens

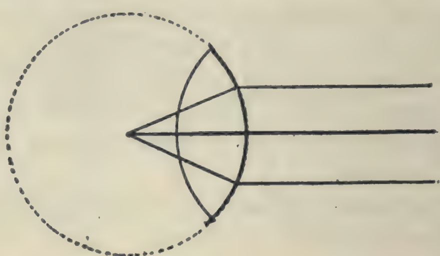


FIG. 6

Showing the focal length of a bi-convex lens to be equal to its radius.

will be converged and brought to a focus. Now the question occurs, where will this focus be located, or what is the focal length of this lens? It depends upon the radius of curvature, which, in turn, is determined by the diameter of the sphere.

Presuming the rays of light were parallel before entering the lens, then its focal length would be equal to the diameter of the sphere. If the lens was bi-convex, with both surfaces of equal curvature, then its focal length would be equal to the radius of the sphere, which is one-half the diameter, as illustrated in Fig. 6.

Suppose the diameter of the sphere to be ten inches, then the radius of curvature of the lens would be five inches; if the lens was plano-convex, its focal length would be ten inches, which is twice the length of its radius; if the lens was bi-convex, its focal length would be five inches, which is just the length of its radius

Therefore, we say that the focal length of a plano-convex lens is equal to twice the length of its radius, and of a bi-convex lens is equal to its radius.

In order that the relation between the curvature of the surface of a lens and its focal length may be better understood, a few words may be allowed on the measurement of curvature in general.

The smaller the radius of a circle, the greater will be the curvature of the circle itself, and conversely the larger the radius the less the curvature of the circle. A portion of a circle of five-inch radius will be more curved than a like portion of a circle of ten-inch radius; in fact, it is exactly twice as much curved. A doubling of the radius causes a halving of the curvature or, in other words, the curvature of a surface is inversely proportioned to the radius.

Therefore, the curvature of any surface is described by the reciprocal of the radius of that surface. (For the benefit of our less-advanced readers we would say that a reciprocal of any quantity is the quotient arising from the division of a unit by that quantity. Thus, the reciprocal of 4 is ¼.) By universal agreement the meter has been chosen as the length of radius that should be taken as a standard. Hence the unit of curvature is *one dioptre*, which has a radius of curvature of one meter. A curvature of 2 D. will correspond to a radius of half a meter. A curvature of 10 D. will represent a radius of 1/10 meter.

As the curvature of any surface is proportional to the reciprocal of its radius of curvature, the principle of the lens measure is based on the calculation of that radius from measurement made of its surface. The instrument is so constructed and its dial so graduated that the curvature of the lens it measures can be read off directly in dioptres.

CYLINDRICAL LENSES.

What is a cylindrical lens? Conforming to our definition of a spherical lens, we would answer, "the section of a cylinder."

Or, in other words, a lens that has one or both of its surfaces curved as a portion of a cylinder. Many students have difficulty in forming a proper conception of the shape of a cylindrical lens, and some opticians even are confused in their ideas of this class of

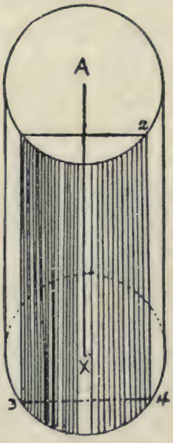


FIG. 7

Showing a glass cylinder, from which a plano-convex cylindrical lens is sliced.

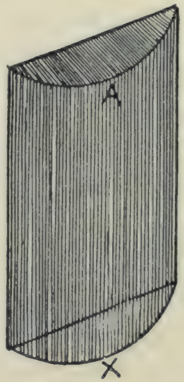


FIG. 8

Showing a plano-convex cylindrical lens.

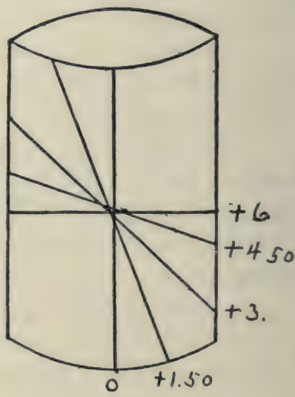


FIG. 9

Showing the difference in refractive power in the several meridians of a cylindrical lens.

lenses; and, therefore, we will endeavor by description and illustration to present the subject in such a light that no one can fail to understand.

Fig. 7 represents a transparent cylinder, presumably made of glass, the axis of which is represented by the line *A X*. From this cylinder a section is made parallel to its axis, the cutting instrument entering at the place of the line *1, 2* and emerging at *3, 4,* producing the plano-cylindrical lens *1, 2, 3, 4,* which is represented as detached in Fig. 8. The axis of this plano-cylindrical lens runs from *A* to *X*, and the figure shows that it is plano and therefore possesses no refractive power. The curvature and, therefore, the optical power, lies in the meridian at right angles to this. In a spherical lens the curvature is the same in all meridians, but in a cylindrical lens the refractive power of the lens varies in each meridian. There are two meridians, in which the optician is most interested, which are called the *two principal meridians,* and they are the meridians of greatest and least refraction, or, in the latter case, of no refraction at all. The meridian of no power and the meridian of greatest power are necessarily at right angles to each other, the other meridians increasing and decreasing in a regular ratio.

This fact may be stated in other words as follows: The refracting power of a cylindrical lens is at its maximum in the meridian directly at right angles to its axis, and is zero in the meridian of its axis, while the intermediate meridians possess intermediate values, increasing as the principal meridian is approached and decreasing toward the axis.

This variation in refractive power in the different meridians of the lens is illustrated in Fig. 9, which is a drawing of a + 6 D. bi-cylindrical lens. In the meridian of the axis the refractive power is nothing. In the meridian at right angles to the axis the full power of the lens is located. In the meridian at right angles to the axis the full power of the lens is located. In the meridian at 45° from axis, one-half the power of the lens is shown, viz., 3 D., while the intermediate meridians show proportional values.

It follows, as a matter of course, that the optical effect of a convex (or a concave) cylindrical lens upon vision, depends not only on the curvature of its surfaces, but also on the direction in which the axis is placed before the eye. If the lens is placed with

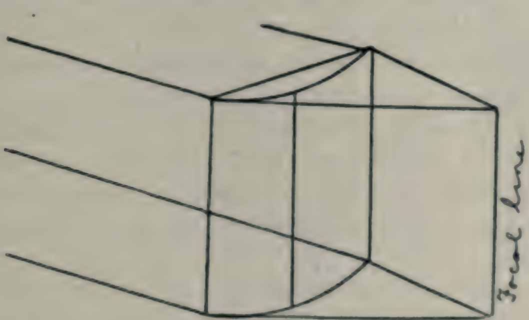


FIG 10

Showing the action of a convex cylinder in refracting the rays at right angles to axis and bringing them to a focal line.

its axis vertical, the rays of light passing through the vertical meridian will be unrefracted and will pass on into space indefinitely; but the rays passing through the horizontal meridian will be bent from each side toward the middle and will meet there and form a vertical focal line, as illustrated in Fig. 10.

If now the lens be turned so that its axis is horizontal, there will be no refraction of light in this meridian, but the rays passing through the vertical meridian will be refracted from above and below, and come to a focus in the middle and form a horizontal focal line.

Therefore, we say that a beam of light passing through a cylindrical lens forms a focal line at the principal focal distance of the lens, such line being parallel to the axis of the lens.

If a stenopaic slit be placed in front of a cylindrical lens, the effect produced will vary according to the position of the slit. If placed parallel to and directly over the axis of the cylinder, the light will suffer no refraction, because it passes through plane glass. If the slit be turned 90°, so as to lie at right angles to the axis, the light is now brought to focus at the principal focal distance of the lens. Therefore, when the slit is placed over the axis of a cylinder, the refractive power of the latter is destroyed, because no light is allowed to pass except through the axis or plane part of the lens.

When two cylindrical lenses of the same power are placed with their axes at right angles to each other, their powers will be combined in such a way that the rays passing through the two principal meridians will be refracted to the same point, which corresponds to the action of a spherical lens, and therefore the two cross cylinders in this position have a spherical value.

From this fact may be deduced the two following laws:

1. Any two cylinders of same sign and same power, with axes at right angles, are equal to a spherical lens of same sign and power.

2. Any spherical lens may be considered as consisting of two cylinders of same sign and power, whose axes will be at right angles.

A clear understanding of these laws is necessary, as they simplify calculations in the various forms of combinations of lenses.

Combinations of lenses having similar signs, that is, when both are plus or both minus, are known as *generic* compounds.

When the signs are dissimilar, that is, when one is plus and the other minus, they are called *contra-generic*.

SPHERO-CYLINDERS.

A spherical and a cylindrical lens may be combined in one, such a combination being practically the union of a plano-sphere and a plano-cylinder joined together by their plane surfaces, because the spherical curvature is ground upon one surface and the cylindrical curvature upon the other surface. Or the spherical and cylindrical curvatures can both be ground upon the same surface, as in the case of a toric lens. It may be stated in passing that the optical value of a lens depends upon the curvature of its surfaces and not upon its thickness.

Suppose a plano-convex spherical lens of 3 D. be united with a plano-cylindrical lens of 2 D., with its axis vertical, as represented by this formula:

$$+3\text{ D. S.} \subset +2\text{ D. cyl. axis } 90^\circ.$$

$$\begin{array}{r|l}
 & \begin{array}{l} +\ 3\text{ D.} \\ \quad \infty \\ \hline +\ 3\text{ D.} \end{array} \\
\hline
 & \qquad\qquad \begin{array}{l} +3\text{ D.} \\ +2\text{ D.} \\ \hline +5\text{ D.} \end{array}
\end{array}$$

According to the law enunciated above, the + 3 D. sphere is equivalent to two + 3 D. cylinders at right angles to each other, and therefore we have a value of + 3 D. in both the vertical and horizontal meridians. Inasmuch as the axis of the cylinder possesses no refractive power, the vertical meridian is unaffected by the combination, and as the full refractive power of the cylinder lies in the meridian at right angles to the axis, the horizontal meridian represents the combined values of the two lenses, as shown in the diagram above.

Suppose a plano-convex sphere of 2 D. be united with a plano-concave cylinder of 1 D. with its axis horizontal, as represented by the following formula:

$$+2\text{ D. S.} \subset -1\text{ D. cyl. axis } 180^\circ.$$

$$\begin{array}{r|l}
 & \begin{array}{l} +2\text{ D.} \\ -1\text{ D.} \\ \hline +1\text{ D.} \end{array} \\
\hline
 & \qquad\qquad \begin{array}{l} +2\text{ D.} \\ \quad 0 \\ \hline +2\text{ D.} \end{array}
\end{array}$$

This gives us a value of + 2 D. in both meridians, imparted by the sphere of that sign and power. The vertical meridian is partially neutralized by the cylinder and is reduced to + 1 D., while the horizontal meridian, in which the axis lies, is unchanged and remains + 2 D.

The first of these illustrations is a generic compound, and the second a contra-generic one, but the latter can be converted into the former, as a study of the contra-generic formula shows that it has a generic equivalent as follows:

$$+ 1 \text{ D. S.} \bigcirc + 1 \text{ D. cyl. axis } 90^\circ$$

TRANSPOSITION.

Transposition means a change in the form or curvature of a lens without any alteration in its value or refractive power. This is a subject that seems to have been regarded as difficult of comprehension and execution, because the same results may be attained by different methods, and this has brought forth many rules by the various authorities, such rules being more or less cumbersome and complicated. Transposition is not an empirical matter that depends on the dictum of any authority, but is really one of exact mathematical calculation.

A comparison may be made between transposing the form of a lens and still retaining its original refractive power, and changing the form of money and still retaining its original value. A five-dollar bill may be changed into five one-dollar bills, into ten fifty-cent pieces, into twenty quarters, into fifty dimes, or into five hundred pennies, but the five-dollar value still remains and will not be impaired by any of these changes. So the curvature of the two surfaces of a lens may be changed in several ways, but so long as the relations of these curvatures to each other are maintained, the refractive power of the lens remains the same.

The object of transposition is threefold:

1. To simplify calculations.
2. To reduce curvatures.
3. To lessen cost of grinding the lens.

Preference is naturally given to the simpler, less expensive form of lens than to the more complicated, higher-priced form, although there are cases where it may be desirable to change a simple into a more complex form for certain reasons, as, for instance, if a plane cylinder is called for with its axis horizontal. When the patient directs his eyes downward he gets a prismatic effect, the base being upward in a convex cylinder and downward in a concave. If such a plane cylinder be transposed to a sphero-cylinder, the axis of the cylinder will then be in a vertical position, and there can be no prismatic action when patient looks up or down.

TRANSPOSITION OF SPHERICAL LENSES.

The refractive power of a spherical lens depends upon the sum of the curvatures of its two surfaces. The total curvatures of its surfaces may be made up in several different ways to produce the same value, as illustrated in Figs. 3 and 4 on page 160.

If an optician is asked for a + 6 D. spherical lens he can furnish any of the four forms shown in Fig. 3, and if asked for a — 6 D. spherical lens, any one of the four forms illustrated in Fig. 4. In all of them the curvatures of the two surfaces vary, but in every one of them the sum of the two surfaces is equal to 6 D.

Transposition of a spherical lens is a comparatively simple matter, and is governed by the fact that it is easily understood and remembered, viz., that the sum of the two surfaces must always equal the exact amount of curvature desired.

Sometimes a particular shape of lens is preferred, as, for instance, the periscopic, which possesses the advantages of allowing more room for the play of the lashes and affording a wider field of vision. If a prescription was sent to the manufacturing optician for a pair of spectacles fitted with — 2 D. lenses, he would furnish periscopic lenses (because they are considered preferable) with concave surfaces — 3.25 D., and convex surfaces + 1.25 D. (because 1.25 D. is the customary curvature of the lesser surface of the periscopic lenses). The writer, who wears this number for distance, had his lenses made as follows: Concave surface — 6 D. and convex surface + 4 D., which affords a decided periscopic shape and effect.

The transposition of spherical lenses is subject to two rules, depending on whether the surfaces are alike or unlike.

Rule 1. In double lenses, where the surfaces are alike (both convex or both concave), if the curvature of one surface is increased by any particular amount, the curvature of the other surface must be decreased by exactly the same amount, so that the sum of the two will be always the same.

Rule 2. In periscopic lenses, where the surfaces are unlike (one is always convex and the other always concave), if the curvature of one surface is increased or decreased by any particular amount, the curvature of the other surface must be increased or decreased by exactly the same amount, so that the difference between the two shall be always the same.

In the ordinary methods of determining the strength of a convex lens, by measuring its focal distance or by neutralization, we learn only the total refractive value of the two surfaces, with no indication as to the separate value of each surface. By the above methods the forms *A, B, C* and *D* would each show a refractive value of + 6 D., but no knowledge as to the particular difference between them.

In order to determine the curvature or the value of each surface, recourse must be had to the lens measure, which is really a spherometer, and is so constructed that when it is pressed against the surface of a lens, the dial indicates the amount of curvature of that surface. The sum of the two surfaces, adding when signs are alike and subtracting when signs are unlike, will indicate the value of the lens.

ADDITION AND SUBTRACTION.

In order that these articles may lack nothing in clearness, it may perhaps be well to make a few explanatory remarks about algebraic addition and subtraction.

Addition is the process of finding the sum of two or more algebraic numbers.

If the numbers to be added are all positive, the algebraic sum is also positive and equal in amount to the number of positive units.

If the numbers are all negative, the sum is also negative and equal in amount to the number of negative units.

If one of the numbers to be added is positive and the other negative, then the algebraic sum is:

1. Positive, if the positive units are in excess and equal to the amount of such excess.

2. Negative, if the negative units are in excess and equal to the amount of such excess.

3. Zero, if the positive and negative units are equal in amount.

For illustration:

$$+5 \text{ and } +3 = +8$$
$$-5 \text{ and } -3 = -8$$
$$+5 \text{ and } -3 = +2$$
$$-5 \text{ and } +3 = -2$$
$$-3 \text{ and } +3 = 0$$

Subtraction is the process of finding the difference between two numbers, or the number of units which lie between the two numbers.

If the numbers to be subtracted are both positive, or both negative, the result will be either positive or negative respectively, and will equal the difference between the two numbers.

If the numbers to be subtracted are one negative and the other positive, then the subtraction of a positive number from a negative number is equivalent to adding an equal negative number, and the subtraction of a negative number from a positive is equivalent to the addition of an equal positive number.

From these facts is deducted the following

RULE.

Change the sign of the subtrahend (that is, the number to be subtracted) and proceed as in addition.

For illustration:

Subtract	-3	from	$+5$	$= +8$
"	$+3$	"	-5	$= -8$
"	$+3$	"	$+5$	$= +2$
"	-3	"	-5	$= -2$

POWERS OF THE SEVERAL MERIDIANS.

In a spherical lens the curvature is the same in each and every meridian, and hence there are no principal powers, but the number of the lens represents its power in any and all meridians. But when a cylindrical element is introduced into a lens there are meridians of varying curvatures increasing in a regular gradation from the longest to the shortest curve and decreasing again in the same ration. The meridians of least and greatest curvature represent the principal powers of the lens. There are three forms of cylinders, as follows:

$$\left.\begin{array}{l}\text{Plano-}\\ \text{Sphero-}\\ \text{Cross-}\end{array}\right\}\text{Cylinders,}$$

in each of which there are two principal meridians or powers.

1. One principal power is zero and the other convex or concave. For instance:

Zero at 90° and + 2 D. at 180°.

These powers are found in two forms:

(*a*) A plano-cylindrical lens, of + 2 D. with its axis at 90°.

(*b*) A sphero-cylindrical lens, the sphere being + 2 D. and the cylinder being — 2 D. with its axis at 180°.

2. The powers, both convex or both concave, of different degrees.

(*a*) That which is represented by the power of the sphere alone, lying in the meridian corresponding to the axis of the cylinder.

(*b*) That which is represented by the algebraic sum of the powers of the sphere and cylinder, lying in the meridian at right angles to the axis of the cylinder.

For example:

+ 1 D. at 90° and + 2 D. at 180°.

This occurs in the form of a sphero-cylinder, of which there may be two varieties; or a cross-cylinder.

A. The sphere being the lower of the two powers desired, and the cylinder being the difference between the two powers, with its axis in the meridian of least power.

B. The sphere being the higher of the two powers, and the cylinder being the difference between the two powers, with its axis in the meridian of greatest power.

C. A cross-cylinder, each cylinder representing one of the principal powers, with its axis at right angles to the meridian in which that power is desired.

This is shown in the following formulæ, each one of which is the optical equivalent of the other:

A. + 1 D. S. $\frown$ + 1 D. cyl. axis 90°.
B. + 2 D. S. $\frown$ — 1 D. cyl. axis 180°.
C. + 1 D. cyl. axis 180° $\frown$ + 2 D. cyl. axis 90°.

If the principal powers are concave, as for example,

— .50 D. at 180° and — 1.50 D. at 90°,

they will be obtained in the three following combinations:

— .50 D. S. ⊂ — 1 D. cyl. axis 180°.
— 1.50 D. S. ⊂ + 1 D. cyl. axis 90°
— .50 D. cyl. axis 90° ⊂ — 1.50 D. cyl. axis 180°.

3. The two powers, one convex and the other concave, of the same or different numbers. For example:

— 1.50 at 90° and + 2.50 at 180°.

These powers can be put up, as in the previous case, in three forms, two sphero-cylinders and a cross-cylinder.

A. The sphere being the number of the concave power and the cylinder being the sum of the two powers, with the sign of the convex and the axis at right angles to it.

B. The sphere being the number of the convex power and the cylinder the sum of the two powers, with the sign of the concave and the axis at right angles to it.

C. A cross-cylinder, one surface convex and the other concave, each cylinder representing one of the principal powers, with its axis at right angles to the meridian in which that power is desired.

These three conditions are represented in the following formulæ, which are interchangeable:

A. — 1.50 D. S. ⊂ + 4 D. cyl. axis 90°.
B. + 2.50 D. S. ⊂ — 4 D. cyl. axis 180°.
C. — 1.50 D. cyl. axis 180° ⊂ + 2.50 D. cyl. axis 90°.

PLANO-CYLINDERS.

On page 164 will be found a drawing of a plano-cylindrical lens (Fig. 8), which shows that it is a section of a cylinder and that it has no curvature in the meridian of its axis. Another drawing (Fig. 9) shows that the curvature commences as the axis is departed from and increases until the meridian at right angles to axis is reached, where it is at a maximum, and then gradually decreases again.

Such a lens may also be represented by a diagram, in which a dotted line and a black line will stand for the two principal meridians, or the meridians of no curvature and of greatest curvature, the former indicating the axis of the lens and the latter its full refractive power.

At Figs. 11 and 12 we illustrate two such diagrams as above referred to.

Fig. 11 represents a plano-cylindrical lens, + 1 D. cyl. axis 90°, and Fig. 12 a plano-cylindrical lens, — 2 D. cyl. axis 180°.

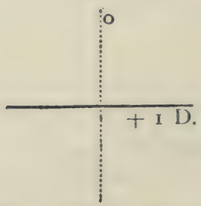


FIG. 11

Showing axis of cylinder vertical and refractive power in horizontal meridian.

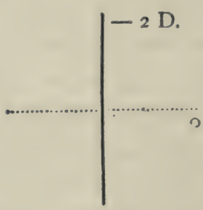


FIG. 12

Showing axis of cylinder horizontal and refractive power in vertical meridian

A plano-cylindrical lens may be recognized by the following characteristics:

There is one meridian, and only one, in which the lens can be moved that no motion of an object looked at occurs. This is the meridian of its axis, and in every other meridian there is motion, more or less marked, as the axis is departed from.

When a circle is viewed through a cylinder, it is elongated into an oval: if the cvlinder is concave, in the direction of its axis; if convex, at right angles to axis.

When a straight line is viewed through a cylinder, rotation of the lens causes the line to break, going with or from the axis of the cylinder as the cylinder is concave or convex.

TRANSPOSITION OF PLANO-CYLINDERS.

A plano-cylinder may be converted into a sphero-cylinder; and conversely a certain form of sphero-cylinder into a plano-cylinder.

Rule 3—To transpose a plano-cylinder into a sphero-cylinder: the sphere is obtained by taking the number of the cylinder and retaining its sign, while the cylinder retains the same number, but its sign is opposite and its axis at right angles to that of the original cylinder.

For example, we take the following plano-cylinders:

+ 1 D. cyl. axis 90°.
— 1.50 D. cyl. axis 180°

which we wish to transpose into sphero-cylinders. By carefully following the rule as given above, the results will be:

+ 1 D. S. ⌒ — 1 D. cyl. axis 180°.
— 1.50 D. S. ⌒ + 1.50 D. cyl. axis 90°.

Rule 4.—To transpose a sphero-cylinder into a plano-cylinder, which can be done only when the sphere and cylinder are of the same number but of unlike signs. The algebraic addition of such sphere and cylinder gives zero as the result, which shows that there is no sphere. The cylinder retains its number, but its sign changes and its axis is at right angles to the original cylinder.

For example:

— 2 D. S. ⌒ + 2 D cyl. axis 90°.
+ 1.50 D. S. ⌒ — 1.50 D. cyl. axis 180°

can be transposed according to above rule into

— 2 D. cyl. axis 180°.
+ 1.50 D. cyl. axis 90°.

Rule 5.—Two plano-cylinders of same sign and with axes parallel, are equal to one cylinder whose power is the sum of the two, with same sign and axis.

For example:

+ 1 D. cyl. axis 90° ⌒ + .50 D. cyl. axis 90° = + 1.50 D. cyl. axis 90°.

— 1.50 D. cyl. axis 180° ⌒ — 1.25 D. cyl. axis 180° = — 2.75 D. cyl. axis 180°.

Rule 6.—Any plano-cylinder may be divided into two plano-cylinders of same sign and axis, whose combined power is equal to the original:

For example:

+ 2 D. cyl. axis 90° = + 1.25 D. cyl. axis 90° ⌒ + 75 D. cyl. axis 90°.

— 2.50 D. cyl. axis 180° = — 1.50 D. cyl. axis 180° ⌒ — 1 D. cyl. axis 180°.

Rule 7.—Two plano-cylinders, of unlike signs, but with axes parallel, are equal to one plano-cylinder whose power is the difference between the two, with same axis and the sign that of the greater of the two.

For example:

+ 2.50 D. cyl. axis 90° ⊃ — 1.25 D. cyl. axis 90° = + 1.25 D. cyl. axis 90°.

—3.25 D. cyl. axis 180° ⊃ + 1.50 D. cyl. axis 180° = — 1.75 D. cyl. axis 180°.

Rule 8.—Two plano-cylinders of same power and axis, but of unlike signs, are equal to a plano lens.

For example:

+ 1.25 D. cyl. axis 90° ⊃ — 1.25 D. cyl. axis 90° = 0.

— 1.50 D. cyl. axis 180° ⊃ + 1.50 D. cyl. axis 180° = 0.

SPHERO-CYLINDERS.

There are three forms of sphero-cylindrical lenses, which may be designated as simple, compound and mixed.

1. A contra generic sphero-cylinder, in which the numbers are the same but the signs are unlike.

For example:

+ 1.25 D. S. ⊃ — 1.25 D. cyl. axis 180°.

Fig. 13 shows the spherical surface of the lens with a refractive power of + 1.25 D. in both the vertical and horizontal me-

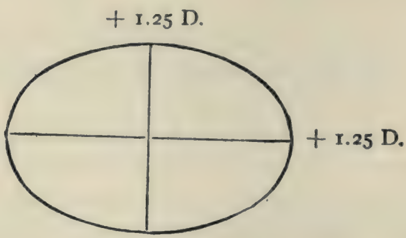


FIG. 13

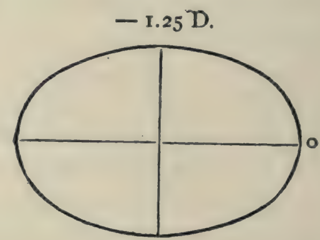


FIG. 14

ridians. Fig. 14 shows the cylindrical surface of the lens with a refractive power of — 1.25 D. in the vertical meridian and zero in the horizontal. When these two surfaces are in opposition, the vertical meridian of one exactly neutralize the vertical meridian of the other, while in the horizontal meridian 0 added to + 1.25 = + 1.25 in this meridian.

2. (A) A sphero cylindrical lens in which both the sphere

and cylinder have the same sign—that is, both convex or both concave, but the sphere has the greater power.

For example:

+ 2 D. S. $\bigcirc$ + 1 D. cyl. axis 90°.

The values of the vertical and horizontal meridians of this

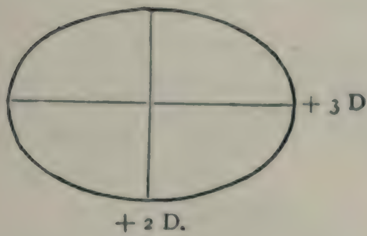


FIG. 15

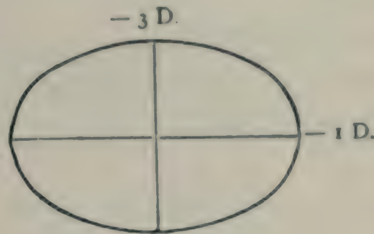


FIG. 16

lens are shown in the above figure. The + 2 D. sphere contributes + 2 D. in both meridians while the + 1 D. cyl. axis 90° adds nothing to the vertical meridian, and + 1 D. to the horizontal. Therefore, the refractive power of the vertical meridian is + 2 D. and of the horizontal meridian + 3 D.

(B) A sphero-cylindrical lens in which both the sphere and cylinder have the same sign—that is, both convex or both concave, but the cylinder has the greater power.

For example:

— 1 D. S. $\bigcirc$ — 2 D. cyl. axis 180°.

The values of the vertical and horizontal meridians of this lens are shown in the above diagram. The — 1 D. sphere contributes — 1 D. in both meridians, while the — 2 D. cyl. axis 180° adds nothing in the meridian of this axis and — 2 D. in the meridian at right angles, that is, in the vertical. Therefore, the refractive power of the vertical meridian is — 3 D. and of the horizontal — 1 D.

3. (A) A sphero-cylindrical lens in which one principal power is convex and the other concave, as a result of the sphere and cylinder having unlike signs, and the sphere having the greater power.

For example:

+ 2 D. S. $\bigcirc$ — 1 D. cyl. axis 180°.

The + 2 D. sphere contributes + 2 D. in both the vertical and horizontal meridians, while the — 1 D. cyl. axis 180° partially neutralizes the vertical meridian and reduces it to + 1 D., while it leaves the meridian of its axis unaffected at + 1 D.

(B) A sphero-cylindrical lens, in which one principal power is convex and the other concave, as a result of the sphere and cylinder having unlike signs, and the cylinder having the greater power.

For example:

— 1 D. S. ⊃ + 2 D. cyl. axis 90°.

The — 1 D. sphere contributes — 1 D. in the vertical and horizontal meridians, while the + 2 D. cyl. axis 90° overcomes the

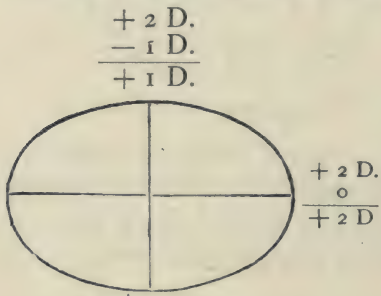


FIG. 17

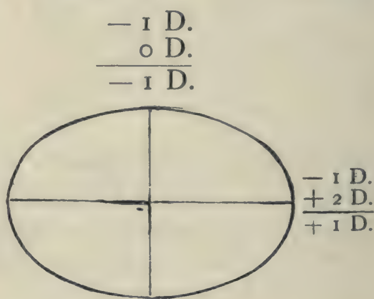


FIG. 18

— 1 D. in the horizontal meridian and substitutes + 1 D. in its place, and at the same time leaves the meridian of its axis unaffected at — 1 D.

TRANSPOSITION OF SPHERO-CYLINDERS.

The transposition of sphero-cylindrical lenses is governed by the following rules:

Rule 9.—The sphere is obtained by the algebraic addition of the sphere and cylinder.

Rule 10.—The power of the cylinder remains the same as the original, but its sign changes and its axis is turned to right angles.

Practical applications of the above rules:

1. A sphero-cylindrical lens, in which the sphere and cylinder have the same number but unlike signs:

+ 1.25 D. S. ⊃ — 1.25 D. cyl. axis 180°.

The algebraic addition of + 1.25 D. and — 1.25 D., in order to obtain the sphere, shows nothing as the result, which means that the sphere is neutralized and dropped.

To obtain the cylinder in this case we change the sign from — to +, and the axis from 180° to 90°, as for example:

+ 1.25 D. S. ⊂	— 1.25 D. cyl. axis 180°.
— 1.25 D. C.	change sign and axis.
0	+ 1.25 D. cyl. axis 90°.

2. (A) A sphero-cylindrical lens, in which both the sphere and cylinder have the same sign, the spherical power being greater than that of the cylinder + 2 D. S. ⊂ + 1 D. cyl. axis 90°.

To obtain the sphere, the algebraic addition of + 2 D. and + 1 D. equals + 3 D. S.

To obtain the cylinder, we change the sign from + to —, and the axis from 90° to 180°, equaling — 1 D. cyl. axis 180°, as for example:

+ 2 D. S. ⊂	+ 1 D. cyl. axis 90°.
+ 1 D. C.	change the sign and axis.
+ 3 D. S. ⊂	— 1 D. cyl. axis 180°.

(B) A sphero-cylindrical lens, in which both the sphere and the cylinder have the same sign, the cylindrical power being greater than that of the sphere,

— 1 D. S. ⊂ — 2 D. cyl. axis 180°.

To obtain the sphere, the algebraic addition of — 1 D. and — 2 D. equals — 3 D. S.

To obtain the cylinder, we change the sign from — to +, and the axis from 180° to 90°, equaling + 2 D. cyl. axis 90°, as for example:

— 1 D. S. ⊂	— 2 D. cyl. axis 180°.
— 2 D. C.	change sign and axis
— 3 D. S. ⊂	+ 2 D. cyl. axis 90°.

3. (A) A sphero-cylindrical lens, in which the sphere and the cylinder have unlike signs, the former having the greater power,

+ 2 D. S. ⊂ — 1 D. cyl. axis 180°.

The algebraic addition of + 2 D. and — 1 D. gives + 1 D.

as the value of the sphere, while the sign of the cylinder changes from — to +, and its axis from 180° to 90°, as for example:

+ 2 D. S. ⊃ — 1 D. cyl. axis 180°.
— 1 D. change sign and axis.

+ 1 D. S. ⊃ + 1 D. cyl. axis 90°.

(B) A sphero-cylindrical lens, in which the sphere and cylinder have unlike signs, the latter possessing the greater power,

— 1 D. S. ⊃ + 2 D. cyl. axis 90°.

The algebraic addition of — 1 D. and + 2 D. gives + 1 D. as the power of the sphere, while the sign of the cylinder changes from + to —, and its axis from 90° to 180°, as for example:

— 1 D. S. ⊃ + 2 D. cyl. axis 90°.
+ 2 D. change sign and axis.

+ 1 D. S. ⊃ — 2 D. cyl. axis 180°.

CROSS CYLINDERS.

A cross cylindrical lens is composed of two cylinders with their axes at right angles to each other.

There are two forms of cross cylinders, as follows:

1. When both cylinders have like signs, as for example:

+ 2 D. cyl. axis 90° ⊃ + 3 D. cyl. axis 180°.

2. When the two cylinders are of unlike signs, as for example:

+ 1 D. cyl. axis 90° ⊃ — 2 D. cyl. axis 180°.

The two principal powers of a cross cylindrical lens are represented by its two components, and lie at right angles to their respective axes.

In the first form, when both cylinders are of the same power and have the same sign, they are equivalent to a sphere of the same power and sign, as for example:

+ 2 D. cyl. axis 90° ⊃ + 2 D. cyl. 180° = + 2 D. S.

TRANSPOSITION OF CROSS CYLINDERS.

The transposition of cross cylinders is governed by the following rules:

Rule II.—The sphere may be either one of the cylinders with its proper number and sign.

Rule 12.—The cylinder is obtained by the algebraic subtraction of one original cylinder from the other, with the sign and axis of that cylinder which was not converted into the sphere.

Inasmuch as either one of the original cylinders can be used for the sphere, it follows that there are always two forms of sphero-cylindrical equivalents for every cross cylinder, except when they are alike as to number and sign, in which case their equivalent is a sphere of the same number and sign.

Practical applications of the above rules.

1. A cross cylinder in which the signs are alike, as for example:

+ 2 D. cyl. axis 90° $\asymp$ + 3 D. cyl. axis 180°.

By following the rule we take the first cylinder for the sphere, which gives + 2 D. S.

The cylinder is obtained by the algebraic subtraction of + 2 D. from + 3 D., which leaves + 1 D. as the number of the new cylinder. Its axis and sign must correspond to the one that was not converted into the sphere, and the result is

+ 2 D. S. $\asymp$ + 1 D. cyl. axis 180°.

Or the + 3 D. may be taken for the sphere, and the cylinder would be the result of the algebraic subtraction of + 3 D. from + 2 D., which would be — 1 D. with the axis of the first cylinder, the result being as follows:

+ 3 D. S. $\asymp$ — 1 D. cyl. axis 90°.

In the first case we have

+ 2 D. cyl. axis 90°	$\asymp$	+ 3 D. cyl. axis 180°.
		+ 2 D.
+ 2 D. S.		+ 1 D. cyl. axis 180°.

In the second case,

+ 2 D. cyl. axis 90°	$\asymp$	+ 3 D. cyl. axis 180°.
+ 3 D.		
— 1 D. cyl. axis 90°	$\asymp$	+ 3 D. S.

While either of these sphero-cylinders is the optical equivalent of the cross cylinder, the first form is the one that would naturally be preferred.

If the cross cylinder was composed of concave cylinders instead of convex, as above, the result would be obtained by the same rules, for example:

— 1.25 D. cyl. axis 135° $\subset\!\supset$ — 1.75 D. cyl. axis 45°

would be transposable into

— 1.25 D. S. $\subset\!\supset$ — .50 D. cyl. axis 45°,

or

—1.75 D. S. $\subset\!\supset$ + .50 D. cyl. axis 135°.

2. A cross cylinder in which the signs are unlike, and, strictly speaking, this is the form that is referred to when a cross cylinder is mentioned.

For example:

+ 1.50 D. cyl. axis 90° $\subset\!\supset$ — 2.50 D. cyl. axis 180°.

The same rules apply in this case for determining the sphere and the cylinder, and in regard to the latter we will refresh the mind of the reader by repeating the rule for subtraction as follows: "Change the sign of the subtrahend and proceed as in addition."

+ 1.50 D. cyl. axis 90° $\subset\!\supset$	— 2.50 D. cyl. axis 180°
	+ 1.50 D.
+ 1.50 D. S. $\subset\!\supset$	— 4 D. cyl. axis 180°

or

+ 1.50 D. cyl. axis 90° $\subset\!\supset$	— 2.50 D. cyl. axis 180°
— 2.50 D.	
+ 4 D. cyl. axis 90° $\subset\!\supset$	— 2.50 D. S.

TRANSPOSITION OF SPHERO-CYLINDERS INTO CROSS CYLINDERS

Any sphero-cylinder may be transposed into an equivalent cross cylinder, in accordance with the following rules:

Rule 13.—The sphere becomes a cylinder, retaining its number and sign, with its axis at right angles to that of the cylinder in the original formula.

Rule 14.—The other cylinder will have the number and sign that results from the algebraic addition of the sphere and cylinder of the original formula, with the corresponding axis of the latter.

Practical applications of the above rules.

1. A generic sphero-cylinder.

$$+ 1 \text{ D. S.} \supset + 1.25 \text{ D. cyl. axis } 90°.$$

By following rule 13 we have as the first cylinder + 1 D. cyl. axis 180°.

By following rule 14 we have for the second cylinder, + 2.25 D. (as the algebraic addition of + 1 D. and + 1.25 D.) cyl axis 90°.

$$\begin{array}{ll} + 1 \text{ D. S.} \supset & + 1.25 \text{ D. cyl. axis } 90°. \\ & + 1 \text{ D.} \\ \hline + 1 \text{ D. cyl. axis } 180° \supset & + 2.25 \text{ D. cyl. axis } 90°. \end{array}$$

Inasmuch as the sphere is equal to two cylinders of the same sign and number with axes at right angles, we have the following sum:

$$\begin{array}{l} + 1 \text{ D. S.} = + 1 \text{ D. cyl. axis } 90° \\ \supset + 1 \text{ D. cyl. axis } 180° \\ \text{combined with } + 1.25 \text{ D. cyl. axis } 90°. \\ \hline + 1 \text{ D. cyl. axis } 180° \supset 2.25 \text{ D.} \\ \quad \text{cyl. axis } 90°. \end{array}$$

2. A contra-generic sphero-cylinder, + 1 D. S. ⊃ — 2 D cyl. axis 180°.

According to rule 13 we have for the first cylinder

$$+ 1 \text{ D. cyl. axis } 90°.$$

According to rule 14 we have for the second cylinder — 1 D (as the algebraic addition of + 1 D. and — 2 D.) cyl. axis 180°

$$\begin{array}{ll} + 1 \text{ D. S.} \supset & - 2 \text{ D. cyl. axis } 180° \\ & + 1 \text{ D.} \\ \hline + 1 \text{ D. cyl. axis } 90° \supset & - 1 \text{ D. cyl. axis } 180° \end{array}$$

Or if we reduce the sphere to its component cross-cylinders, the problem will be worked out thus:

$$\begin{array}{l} + 1 \text{ D. S.} = + 1 \text{ D. cyl. axis } 90° \supset \\ + 1 \text{ D. cyl. axis } 180° \\ \text{combined with } - 2 \text{ D. cyl. axis } 180°. \\ \hline + 1 \text{ D. cyl. axis } 90° \supset - 1 \text{ D. cyl. axis } 180°. \end{array}$$

PROVING TRANSPOSITIONS.

Transposition simply changes the relations of the two surfaces of a lens to each other without altering their combined value. Therefore the formula that would neutralize the original lens would also serve to neutralize the transposed form. The algebraic addition of the neutralizing lenses and the original combination will equal zero, as will also their addition to the transposed formula.

For example:

+ 2.50 D. S. ⊃ + 1.50 D. cyl. axis 90°

which can be transposed into

+ 4 D. S. ⊃ — 1.50 cyl. axis 180°.

The neutralizing formula for the original combination is

— 2.50 D. S. ⊃ — 1.50 D. cyl. axis 90°.

If these be added to the original we have

+ 2.50 D. S. ⊃ + 1.50 D. cyl. axis 90°
— 2.50 D. S. ⊃ — 1.50 D. cyl. axis 90°
―――――――――――――――――――
0 0

and if added to the transposition

+ 4 D. S. ⊃ — 1.50 D. cyl. axis 180°
— 2.50 D. S. ⊃ — 1.50 D. cyl. axis 90°
―――――――――――――――――――

Inasmuch as the — 1.50 D. cyl. axis 180° combined with — 1.50 D. cyl. axis 90° equals — 1.50 D. S., the result is

+ 4 D. S. ⊃ — 2.50 D. S. ⊃ — 1.50 D. S.

which can be simplified into

+ 4 D. S. ⊃ — 4 D. S. = 0.

OBLIQUELY CROSSED CYLINDERS.

A lens with two obliquely crossed cylindrical curvatures is a useless and foolish combination, because it has been proven that there can be no combination at any oblique angle that is not equivalent to two other cylinders whose axis would be at right angles, or to a sphero-cylinder. No matter what inclination the two cylinders may bear to each other, they must result in two curvatures of least and greatest refraction, which are necessarily at right angles to each other.

TOROIDAL OR TORIC LENSES.

A toroidal surface is one that presents two meridians of different curvature at right angles to each other.

Let Fig. 19 represent a section of a bicycle tire, of which the diameter of the wheel itself is two feet and of the tire two inches;

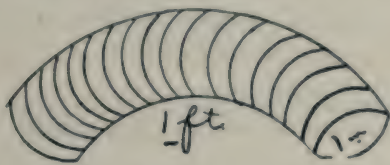
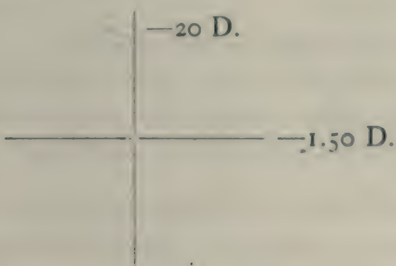


FIG. 19

the radius of curvature in the horizontal meridian would be one foot and the vertical meridian one inch. These are two distinct curvatures and they are at right angles to each other.

If a tool of this shape was used as a grinding surface, the result would be a concave toroidal surface, the power of which in the two meridians would be as follows:



Such a surface resembles very much the bowl of a spoon. The optical value of a toric lens can be equally obtained by using the respective cross cylinders or their equivalent sphero-cylindrical combination. Some authorities claim that there is no optical advantage in the toric form of lens; while there is the great disadvantage of requiring special costly tools to grind each separate form of toric lens.

There is one thing to be said in favor of this form of lens, and that is the curvatures of a compound lens can be more equally divided between the two surfaces than is possible in the usual form of sphero-cylindrical lens.

For example, if the examination showed that any certain case was corrected by the following formula:

— 10 D. S. ⊂ — 1 D. cyl. axis 180°,

all of the spherical curvature would be on one side (that is, 10 D.) and the cylindrical curvature on the other side (that is — 1 D.).

Now in a toric lens the curvature of the two surfaces could be more nearly equalized, as follows:

— 5.50 D. on one surface
— 4.50 horizontal and — 5.50 vertical on other surface.

Another advantage that the toric form of lens presents is that it can be made more periscopic. For example, if + 5 D. is desired at 90° and + 6 D. at 180°, the utmost periscopic effect that could be obtained in the ordinary form of sphero-cylindrical lens would be

+ 6 D. S. ⊂ — 1 D. cyl. axis 180°,

the convex spherical surface being of course placed away from the eye.

It could be made in a toric form to show a greater periscopic effect, as follows:

— 5 D. sphere on one surface
+ 10 D. at 90° and + 11 D. at 180° on other surface.

Or the concave surface can be ground to any curvature, the toric surface being made correspondingly weaker or stronger.

TRANSPOSITION OF SPHERO-CYLINDERS INTO TOROIDALS.

A sphero-cylindrical lens may be transposed into a toric in accordance with the following rules:

Rule 15.—The sphere is obtained by dividing in half the power of the greatest meridian.

Rule 16.—Subtract the strength of this sphere from each of the meridians in turn in order to obtain the power of the two toric curvatures.

PRACTICAL APPLICATION OF THE ABOVE RULES.

1. A generic sphero-cylinder.

+ 7 D. S. ⊂ + 5 D. cyl. axis 90°.

If we divide the greatest meridian (7 + 5 = 12) in half, we obtain + 6 D. as the power for the spherical surface.

Subtract 6 D. from 12 D., and the result will be + 6 D. as the power of the one toric curve: subtract 6 D. from 7 D., and the result will be + 1 D. as the power of the other toric curve. The lens will be

+ 6 D. S. ⌒ toric + 1 D. at 90° and + 6 D. at 180°.

2. A contra-generic sphero-cylinder

+ 5 D. S. ⌒ — 1 D. cyl. axis 180°.

The sphere in this case represents the greatest power, the half of which would be + 2.50 D. S.

Subtract 2.50 from 5 equals + 2.50 D. as the value of one toric curve; subtract 2.50 from 4 equals + 1.50 D. as the value of the other toric curve. The lens will be

+ 2.50 D. S. ⌒ toric + 1.50 D. at 90° and + 2.50 D. at 180°.

TRANSPOSITION OF A TORIC INTO A SPHERO-CYLINDER.

+ 4 D. S. ⌒ + 2 D. at 90° and + 4 D. at 180°.

The sphere represents the power in the meridian of least curvature, which in this case is + 6 D. S.

The cylinder represents the difference between the power of the sphere and that of the meridian of greatest curvature, which in this case would be (4 + 4 = 8 — 6 = 2) + 2 D., with its axis at right angles to the meridian of greatest power. The lens would then be

+ 6 D. S. ⌒ + 2 D. cyl. axis 90°.

CHAPTER VIII.

THE USE AND VALUE OF GLASSES.

Every one knows, in a general way, that spectacles are worn to assist the sight, and there are a large number of persons who know nothing more than that they help the aged to see to read, and the near-sighted to see at a distance. The prejudice against glasses has, on the one hand, acted to deter persons from wearing glasses who really need them; and, on the other hand, has acted to influence employers to decline to engage applicants for work who are spectacled.

It is hardly within the scope of this work, at the present time, to attempt to combat these prejudices or to advance any arguments to prove their fallacy. The first one is so unreasonable that no sensible person in this enlightened day would be rash enough to advise ametropic persons not to wear glasses, nor would the ametrope be so foolish as to listen to such advice. While in regard to the second prejudice mentioned, employers are soon and easily convinced that the man who notices his sight is failing, and promptly uses the means at his command to restore it, is the more wide-awake and capable workman, and does better service than the slothful man who fails to notice his impaired sight, or, if he does, takes no interest or makes no effort to remedy it. The truth of the matter is that, in the hands of a skilful optometrist, there is no means at the present time which will correct so many eye troubles and restore good sight as suitable lenses in all their various combinations, and people have not been slow to find this out and to act in accordance with it.

The common ignorance in regard to glasses and their uses has bred the idea that persons can choose their own glasses; but the fallacy of supposing that the glasses that are the most pleasant for two or three minutes are necessarily the best to use for years, is not so general now as formerly.

Not every one suffers from such a course, and yet the great number that do makes it safer and advisable, in order to avoid any risk, to have the eyes tested by a competent optometrist in even the simplest cases.

Experience has taught the public much in this respect (of the importance of the proper selection of glasses); but there are still many persons who would decidedly object to wearing ill-fitting ready-made clothing, who still do not hesitate, in the infinitely more important and delicate matter of selecting glasses, to purchase them in the old haphazard way without a measurement by oculist or optometrist, without thinking of the danger of thus treating an organ whose mechanism is of the most delicate nature, and whose use is almost as valuable as life itself.

Optical defects requiring the use of glasses may be classified as follows:

1. *Presbyopia*, or old sight; that condition of the eye where there is a deficiency in the power of accommodation of the eye, due to weakening of the ciliary muscles and to hardening of the crystalline lens from age.

2. *Hypermetropia*, or far-sightedness; the eye is too flat, and its refraction is not sufficient to bring parallel rays of light to a focus on the retina.

3. *Myopia*, or near-sightedness; the eye is too long or deep, and its refraction causes parallel rays of light to focus before they reach the retina.

4. *Astigmatism*, or irregular sight; due to an irregularity of the surface of the cornea and a difference in the refraction of its different meridians.

5. *Asthenopia*, or weak sight; due to a weakness of the ciliary muscle or of the recti muscles.

6. *Diplopia*, or double sight; where the two eyes cannot be directed to the same object.

7. A large class of cases where the various colored (non-focal) glasses are required.

8. Another class of cases (not necessarily of optical defect) in workmen, where glasses are needed to protect the eyes from mechanical injury.

Presbyopia and hypermetropia are corrected by convex spherical lenses; astigmatism by convex or concave cylindrical lenses; asthenopia and diplopia by a suitable adjustment or combination of one or more of the above-mentioned kinds, with or without the further combination of prismatic lenses.

Were these results all that could be expected from glasses, their value would be inestimable. But in addition to these optical defects, a great many diseases, dangerous to vision, and dependent upon or caused by these errors of refraction and accommodation, are relieved and cured by the adjustment of the proper lenses. This opens a wide and almost illimitable field of usefulness—a field so extended that it may fairly occupy the undivided time and special study of the most distinguished oculists, and yet in which the educated optometrist can work with satisfaction to his customers and profit to himself.

In that large class of cases where colored glasses are needed, it should be remembered that while no one seems to have any suspicion that such glasses could be in any manner injurious, yet it is essential that great care be exercised in selecting only those which are known certainly to have no focus; otherwise they only increased the irritability of the eye instead of allaying it, especially if the cheap coquilles are worn, as these, being made of moulded or pressed glass, are seldom without a focus (which is generally concave), in addition to which the glass is of poor quality and full of flaws and imperfections, which produce an unpleasant distortion of objects seen through them.

Unless specially desired to correct some error of refraction (in which case the proper focus is ground on a colored lens), tinted glasses should be absolutely without focus, and should not distort or dim objects that are seen through them. The simplest way to determine whether any colored glass is plane or has a focus, is by holding it up to the light and slowly moving it up and down and from side to side while the window-sash or any other stationary object is looked at. If it is a plane glass, and without focus, no movement will be produced on the window-sash by the motion of the glass. On the other hand, if a professedly plane glass is not free from refraction, a motion of the window-sash will be produced by the movement of the lens, either with it or against it, proving it to be in the first case concave, and in the second convex. If there is any such movement, or if the objects are seen imperfect and distorted, the glass should be rejected as not a safe one to wear.

When coquille glasses have a negative meniscus (as is usually the case), and are worn for the relief of irritable and sensitive eyes by a hypermetropic person (as is often the case), it is easy to see how an aggravation of the trouble will be produced, instead of an amelioration; because the hypermetropia, which was the cause of the irritability of the eyes, would be increased by the use of concave lenses, and a further cause of irritation be added.

It is allowable to grind colored lenses with a *weak* focus when required, but there is a great objection to strong numbers, where one part of the lens is much thicker than other parts, and where the thick part would, consequently, be very much darker than the thin part; this would cause the optical center of the lens in convex glasses to be the darkest, and in concave glasses to be the lightest.

Ladies often find the protection of a veil preferable to colored glasses; and in the case of children, the broad brim of a straw hat, lined with some dark material, may answer every purpose.

Sunlight, or white light, is the natural stimulus to the nervous elements of the retina of a healthy eye, and as such should be easily borne without being modified. But as there are many eyes that are a little weak and irritable, and as there are many places where the glare of the sunlight is excessive (as at the seashore or on newly fallen snow), colored glasses always will be more or less used

Formerly green protective glasses were prescribed by oculists, and were in very common use. This color was no doubt suggested by the color of the grass and trees; but although reflected in this way green is very pleasant and agreeable, when transmitted through glasses it is rather irritating. Green glasses gradually fell into disuse, and are now scarcely seen at all, having been entirely supplanted by blue—possibly because the color of the sky is blue (?), but really because it is the complementary color to yellow, which rays of the spectrum are thought to be most irritating to the retina; and as these rays abound in gas-light, blue glasses would be especially useful in cases of weak eyes which suffer more from use at night, where the harshness or intensity of the gas-light would be pleasantly modified by the blue, which neutralizes the irritating yellow rays. But while such glasses may be required in some few cases, there is serious objection in the large majority of eyes to the long-continued use of glasses of any color, which thus decompose the natural white light, and change or shut out certain colors of the spectrum, and when they are removed leave the retina unduly sensitive to the colors that have been excluded. For these reasons, the best glasses for general use, especially to protect against the glare of excessive sunlight, are those having a neutral tint, and known as neutral gray or London smoke, which do not separate the components of light, but which exclude each color of the solar spectrum in equal proportions, and thus simply diminish or soften the light. At the seashore, one sees the crop of these glasses in full bloom; and while on one hand it seems quite a fad for young people to wear them, on the other hand there are many persons whose eyes are sensitive to excessive glare, who find great comfort in their use, and who really could not enjoy the benefits of sea air without them; and their use in such cases cannot be objected to. As a rule, they should never be worn in the house, nor at any time when the light is not excessive and the need for them is not felt, as otherwise the eye would become accustomed to the diminished light, and would be unable to bear the natural daylight, and thus the difficulty they are intended to remove would only be increased.

The simplest form of spectacles that can be used are those made of plain, clear glasses, for use in employments that expose the eye to injury from flying particles, and are recommended merely to protect the eyes from mechanical injury or excessive light. In many cases ordinary window-glass answers perfectly well, or if greater strength is required, plate-glass may be substituted. But as these latter would be uncomfortably heavy, it has been recommended to use thin, clear mica instead. This idea has been made use of in the latest eye-protector which has been placed on the market, consisting of two oblong plates, with a hinge-like joint over the nose, and fitting closely around the orbit by means of numerous bits of cork arranged at close intervals, and fastened around the head by means of a rubber band.

But a greater amount of protection than can be given by this eye-protector, or by the coquille spectacles, is afforded by the so-called goggles, in which the glasses are built up on all sides with thin wire gauze in such shape as to fit snugly around the orbit, and secured on the head either with a rubber band or by regular steel temples. While these goggles shut out all dirt, dust, and flying particles of every nature, yet serious objection is made to them by competent authorities, on the ground that even though the air does seem to be able to circulate more or less freely through the gauze sides, yet they confine the eyes too closely, heating them and causing them to be half-smothered in a stuffy atmosphere saturated with their own vapors and secretions, and in this way aggravate and perpetuate inflammatory conditions of the eyes and lids, which they are sometimes used to relieve.

In coquille glasses (those shaped like a watch crystal) the surfaces of the glass must be absolutely parallel, as otherwise they act as weak focusing lenses to a noticeable and even annoying degree. This imperfection or defect in glasses of this shape can be obviated only by using glasses which have been correctly ground, instead of moulded, as such glasses are usually made.

Eye-protectors are sometimes sold under the name of millers' or turners' spectacles, with heavy frames, large eyes, and plain white glass, and they are not worn nearly as much as they should be by workmen who are exposed to flying chips, etc. Constant exposure to any danger causes us to underrate its importance, and consequently most workmen take the risk of going without glasses, either because they do not think of the danger or because they dislike the inconvenience of wearing glasses, and, as a result, they often bear the scars of wounds of the cornea. On the principle of locking the stable after the horse is stolen, those workmen who have already lost one eye in this way are easily persuaded thereafter to wear protecting glasses to save the other eye.

A prominent optical firm manufactures what they call Bessemer spectacles, which are a combination of colored lenses, for the use of persons engaged in the manufacture of Bessemer steel, and it is said changes in the flame can be more readily distinguished with their use than with any other glass.

In the correction of any optical defect by the adjustment of glasses, it is of very great advantage to begin wearing them in youth, as the eyes then are in such a condition as to adapt themselves to their use much more readily than in later years. The eyes and glasses become, as it were, one optical instrument, and are almost inseparable. This fact is frequently illustrated in the daily experience of every optometrist, and the ignoring of its teaching causes him no inconsiderable amount of trouble. Patients who somehow worry along (as they are apt to do) with an uncorrected optical defect until middle age, or until the eyes break down in the attempt to do their work without the assistance of the long-needed glasses, experience the greatest difficulty in getting their eyes accustomed to their use when at last they are worn, and almost exhaust their own patience as well as the optometrist's before the glasses become entirely pleasant and comfortable.

CHAPTER IX.

OUTFIT REQUIRED.

1. Optical education.
2. Books of reference.
3. Case of test-lenses.
4. Complete set of test-types.
5. Measuring-stick or metric-rule.
6. Record-book or case-book.
7. Ophthalmoscope.
8. Retinoscope.
9. Prisoptometer or refractometer.
10. Ophthalmometer.
11. Keratoscope.
12. Phorometer.
13. Optical bracket.
14. Perimeter.
15. Ophthalmic cabinet.
16. Lens measure.

OPTICAL EDUCATION.

1. Of the value and necessity of an optical education this is scarcely the place to speak. That an optometrist who professes to be competent to correct the various optical defects he meets in his everyday experience should possess a theoretical as well as a practical knowledge of the whole subject is so self-evident as to need no lengthy argument to prove its soundness. Times have changed, and are changing, and people no longer buy their glasses of ignorant peddlers, nor allow themselves to be coaxed into purchasing the *wonderful* glasses of traveling optical quacks; nor are they even content to go to a store and pick out a pair of cheap spectacles with which they think they can see best for a minute or two. When their eyes ache or their sight blurs, they seek an educated optometrist in whom they have confidence, and expect him to be able to advise them, and prescribe glasses if found to be required.

The necessity for skilled optometrists is apparent everywhere, and the time is at hand when every town and village will have its educated optometrist, and he will be a scarcely less important personage than its physician or dentist. And the next generation will demand still more; the time is coming when the fitting of glasses will be placed under the same legal restrictions as the practice of medicine and dentistry, and when no man will be allowed to call himself an optometrist, and no optometrist will be allowed to adjust glasses for defective vision, until he has pursued a course of study and acquired a diploma, just as the physician and dentist (and even the veterinary surgeon) is required to do before commencing the practice of his profession.

The optometrist of to-day is in the bloom of a business that is growing without limit, but only the educated optometrists will be in a position to pluck its choicest fruits; and hence there is no hesitation (and probably no one will dispute this assertion) in placing an optical education as the first requisite in the outfit required by the practical optometrist.

BOOKS OF REFERENCE.

2. One could easily write a lengthy essay, and present a beautiful argument on the necessity of books to the professional man, that would apply in great measure to the practising optometrist, but lack of space forbids, and the truth of this statement will be admitted, universally, without an argument.

One book, at least, is an absolute necessity, but it will be much better if the optometrist can have recourse to two or three, as in this way he gets the views not of one authority alone, but of different authors on the same subject. To study one book is necessary and important, but to follow this with a reading of several authors gives a breadth and depth of knowledge otherwise unattainable. Different authors treat the same subject differently, and each presents it from a standpoint that is new as well as different, and thus, by a combination of these different views and points, it is possible to gain a thorough and complete knowledge of the whole subject. Even if the views of the different authors do not always present something new, yet the reiteration of the same facts, clothed in different language, impresses them the more deeply on the mind.

The money paid for an optical course, or for books, can not be regarded as spent in the ordinary acceptation of that word; but it represents capital, or an investment, that yields large returns and big percentages every day of practice.

For the further information of our readers, and in order to answer the many inquiries that are constantly received, we give below a list of the books on this subject, all of which are valuable and would enrich the library of the optometrist.

THE OPTOMETRIST'S MANUAL, Vol. II, is a continuation of this volume and covers in minute detail myopia, hypermetropia, astigmatism and muscular anomalies. Price, $3.50.

CLINICS IN OPTOMETRY, by C. H. Brown, M. D. A Manual of Practice for Oculists and Optometrists. Each clinic is an actual case, treated in the presence of a class of students, with every step in the examination and treatment clearly explained. Price, $3.50.

HARTRIDGE ON REFRACTION is the work of an English oculist. The first edition appeared in 1884; other editions followed later. The inch system has been entirely discarded in this book in favor of the metrical system, and, while this cannot be classed as an objection, it limits the usefulness of the work among beginners. It does not touch the anatomy of the eye, but on the principles of optics and the various errors of refraction it is very satisfactory. Price, $2.75.

THE REFRACTION OF THE EYE, including a complete treatise on Ophthalmometry, by A. Edward Davis, M. D. While this book gives many valuable and practical hints in general refraction work, including a copious index of cases to which the reader may refer for assistance in the management of similar cases, yet it is largely devoted to a description of the Ophthalmometer, by the use of which the author claims the majority of cases can be fitted without recourse to a mydriatic. This is a new book of 431 pages. Price, $3.00. (Now out of print.)

ANOMALIES OF REFRACTION AND OF THE MUSCLES OF THE EYE, by Tiffany. This is a valuable book and one that can be recommended. It is profusely illustrated, containing almost two hundred plates, embracing nearly all the instruments and appliances used in examining the refraction of the eye and the muscular equilibrium. It gives special attention to the diagnosis and correction of the various muscular anomalies, and contains a very complete chapter on the ophthalmoscope. Price, $3.00. (Now out of print.)

PHYSIOLOGIC OPTICS, Ocular Dioptrics, Functions of the Retina, Ocular Movements and Binocular Vision, is an extremely valuable book to the refractionist. It is written by Dr. M. Tscherning, the distinguished French scientist, who is recognized as the greatest living authority on this subject. The book embodies not only his own researches, but those of the several hundred eminent investigators, who, in the past hundred years, made the eye their specialty and life study. The gold of all their optical research has been sifted out by the experienced and gifted author, which makes the book the most valuable mine of reliable optical knowledge within reach of ophthalmologists, and the greatest work of the century on physiologic optics. The chapters on Ophthalmometry, Ophthalmoscopy, Accommodation, Astigmatism, Aberration and Entoptic Phenomena, especially contain so much that is new, practical and necessary that no refractionist can afford to be without it. Price, $5.00.

SKIASCOPY. A Treatise on the Shadow Test in its Practical Application to the Work of Refraction, with an Explanation in Detail of the Optical Principles on which it is based. This is the latest and most comprehensive book on the shadow test. It not only explains the test, but expounds fully and explicitly the optical principles underlying it. The book contains 220 pages, with colored plates and sixty-nine illustrations, a glossary of optical terms and their abbreviations. Price, $1.50. (Now out of print.)

OPHTHALMIC LENSES, Dioptric Formulæ for Combined Cylindrical Lenses, The Prism Dioptry, and Other Original Papers, by Charles F. Prentice, M. E., the eminent investigator. The first two papers had formerly been published separately in book form, and the supply becoming exhausted, the author revised them and added the result of more recent research. Combined for the first time with the other valuable and interesting papers, they make a book that is of real practical value to every refractionist, and make up the greatest compilation on the subject of lenses extant. The book contains 110 original diagrams. Price, $3.00.

SPECTACLES AND EYEGLASSES, THEIR FORMS, MOUNTING AND PROPER ADJUSTMENT, by Phillips. This little book is intended to supplement studies in refraction, and to give the student knowledge of the correct placing of the glasses before the eyes. Price, $1.50.

HETEROPHORIAS AND INSUFFICIENCIES, a clinical study by H. H. Seabrook, M. D. This is an instructive little book of 106 pages, giving many important hints in the management of this troublesome class of cases. Price, $1.00.

EYESTRAIN IN HEALTH AND DISEASE, with special reference to the amelioration or cure of chronic nervous derangements without the aid of drugs, by A. L. Ranney, M. D. Contains a consideration of the effect of eyestrain upon the duration of life and its probable effect in the causation of various nervous ailments, as well as a chapter on the tests of vision and ocular movements. 321 pages. Price, $2.00. (Now out of print.)

THE OPHTHALMOSCOPE. A manual for students. Is simple and systematic. By Hartridge. Price, $1.50. (Now out of print.)

THE CLINICAL USE OF PRISMS, AND THE DECENTERING OF LENSES, by Maddox. Price, $1.50. (Now out of print.)

OCULAR MUSCLES, by Maddox. Contains a selection of the best tests for ocular muscles, with new ones by the author. A meritorious work. 427 pages. Price, $3.50.

COLOR-VISION AND COLOR-BLINDNESS, by Jennings. Price $1.00.

EYESIGHT AND HOW TO CARE FOR IT, by Harlan. Price, 50 cents. (Now out of print.)

MOTOR ANOMALIES OF THE EYE. A new classification of the Motor Anomalies of the eye, based upon physiological principles, together with their symtoms, diagnosis and treatment, by Alexander Duane, M.D. 100 pages. Price, $1.25. (Now out of print.)

DEFECTIVE EYESIGHT; the principles of its relief by glasses, by D. B. St. John Roosa, M. D. 190 pages. Price, $1.00. This treatise takes up all the conditions requiring the use of glasses, and indicates in a careful manner the rules for prescribing them.

MUSCULAR ANOMALIES OF THE EYE. A practical handbook by Hansell & Reber. 182 pages. Price, $1.00. This is a very satisfactory work and one which the practical student can make no mistake in purchasing. (Now out of print.)

HAND BOOK OF OPTICS, for students of Ophthalmology, by W. N. Suter, M. D., Washington. 209 pages. Price, $1.00.

OPTICAL DICTIONARY, by Charles Hyatt-Woolf. An Optical and Ophthalmological Glossary of English Terms, Symbols and Abbreviations, Relating to Physical, Physiological and Pathological Optics, Optical and other Instruments of Precision, to which are added a number of general and mathematical expressions.

HAAB'S ATLAS OF OPHTHALMOSCOPY, containing a Treatise on the Ophthalmoscope and 74 Colored Plates, showing the ophthalmoscopic appearances in the various intra-ocular diseases. An invaluable book to the optometrist who wishes to recognize diseased conditions.

ELEMENTARY OPHTHALMIC OPTICS, by Freeland Fergus. Price, $1.50. Published in London.

THE EYE AND THE NERVOUS SYSTEM, by Drs. Posey and Spiller. Price, $6.00. 988 pages. Is claimed to be the only book in the English language covering the ground where ophthalmology and neurology meets. Its value is based on the argument that a knowledge of neurology is indispensable to the eye specialist.

ANATOMY AND PHYSIOLOGY OF THE EYE, by Drs. E. J. Brown and W. D. Zoethout. 240 pages. Price, $1.50. (Now out of print.)

SQUINT; ITS CAUSES, PATHOLOGY AND TREATMENT, by Worth. 229 pages. A unique book based on original observations. Price, $3.50.

A MANUAL OF OPHTHALMOSCOPY, by J. E. Jennings, M. D. 95 Illustrations and one Colored Plate. 180 pages. A very satisfactory book on an important subject.

THE REFRACTION AND MOTILITY OF THE EYE, by Dr. W. N. Suter. Price, $3.50. 390 pages. Illustrated with 101 engravings, in the text and four plates in color. A dependable text-book covering the whole field of optometry.

EYESTRAIN, by Ernest Clarke. 188 pages. Most text-books contain a reference to eyestrain or perhaps a chapter on it, but this book covers the subject in systematic detail.

LESSONS ON THE EYE, by F. L. Henderson, M. D. 205 pages. An elementary book, but a valuable one.

THE PRINCIPLES OF REFRACTION IN THE HUMAN EYE, based on the laws of conjugate foci, by Dr. S. M. Burnett, illustrated by 25 original diagrams, by Charles F. Prentice, M. E. Price, $2.50.

THE KEYSTONE RECORD BOOK OF OPTOMETRIC EXAMINATIONS contains 200 record forms with printed headings, suggesting in the proper order the course of eye examination that should be pursued. Price, $2.00.

This list is not intended to be exhaustive, but includes those books which the writer has found most useful in his work of instructing optometrists.

These books will be furnished by THE KEYSTONE, Philadelphia, Pa., at the prices named, subject to changes by the publishers.

CASE OF TEST-LENSES.

3. No optometrist in these days can expect to make a success of the business of fitting glasses without a test-case of trial-lenses. Every dealer who has many eyes to test, and who wishes to do it carefully and thoroughly (and it should never be done in any other way), soon finds out that it is not convenient or satisfactory to have to depend on the spectacles and eyeglasses that are kept in stock and for sale, and he finds himself compelled, sooner or later, to invest in a test-set. The public, generally, are awakening to a realization of the importance of these matters, and they will certainly prefer to patronize the man who is best prepared to examine their eyes, and they will not be slow to see that this can be better done by the use of test-lenses than by a miscellaneous assortment of spectacles of various numbers strewed around on the counter in confused heaps. Then, again, the testing of each eye separately, which a thorough examination necessitates, cannot, of course, be done by spectacles of similar glasses taken from stock, but can only be done by the use of a set of test-lenses and a trial-frame in which one eye can be excluded at a time.

It can be laid down as an inflexible rule, to which none can take exception, that after the acquisition of a complete knowledge of the whole subject of optics and fitting glasses, the next most important item is the possession of a trial-case and the assertion is none too strong when it is said that no dealer is worthy of the name of optometrist whose outfit does not include a test-case.

Acknowledging that every optometrist *must* have a test-case, the size and cost of the one he should procure will probably depend on the size of the town in which he does business and the amount of attention he expects to give to this department of his store. But the amount paid for it is money well invested, and the larger and better the test-case the more it will add to its owner's reputation for competency, and the better it will enable him to fit his cases, and, as a consequence, the more cases he will have to fit.

One of the advantages of the possession of a set of test-lenses that might be mentioned, is that the user is enabled to ascertain the focus and strength of any simple or compound lens that comes into his hands, by neutralization, which subject has been elaborated at another place on these pages.

A complete trial-case is composed of sample lenses of the various kinds used to correct optical defects (sphericals, cylindricals, prisms), which are placed in the trial-frame before the patient's eye, and are readily changed without taking the frame from the patient's face; the examination in this case being what is called subjective—that is, dependent on the answers given by the patient himself. When the correct lenses are thus determined by trial, the optician, from his stock, can quickly furnish similar lenses set in a suitable frame, if they are spherical, or can grind them if cylindrical or prismatic.

In contradistinction to the subjective examination as above, may be mentioned an examination by the ophthalmoscope, retinoscope and ophthalmometer, which is entirely objective—that is, the optometrist selects the proper lens unaided by the patient's answers, which methods will be described later on.

The trial-case should contain at least thirty-two pairs of convex spherical lenses, and thirty-two pairs of concave spherical lenses of the following numbers:

0.25 D.	2.25 D.	5.00 D.	11.00 D.
0.50	2.50	5.50	12.00
0.75	2.75	6.00	13.00
1.00	3.00	6.50	14.00
1.25	3.25	7.00	15.00
1.50	3.50	8.00	16.00
1.75	4.00	9.00	18.00
2.00	4.50	10.00	20.00

These should be in *pairs*, and both convex and concave. In addition to the spherical lenses, there should be at least eighteen convex and eighteen concave cylindrical lenses, numbered from .25 D. to 6 D. The cylinders do not run above this, as it is very rare that a stronger one is required. These may be single, but it is much more satisfactory to have them in pairs.

The case should also contain about ten prismatic lenses (plane prisms, without any focus), numbering from one degree to twenty degrees.

Besides these, the case contains usually a few colored lenses —light blue and dark blue, and light red and dark red; also a plane glass, a ground glass, and a glass with one-half the circle clear and plane and the other half ground or frosted. Also several metal disks, one of which is solid, to be used to exclude one eye while the other is being tested. Another has a minute perforation in its center, called the "pin-hole" disk, which is to be used in any case of imperfect vision to determine whether the impaired vision can be corrected by glasses or whether it is due to organic disease and beyond the reach of glasses. If the pin-hole disk improves vision, then the sight can be restored to an equal degree by properly adjusted glasses. If the pin-hole disk causes no improvement in the appearance of the letters on the test-card hanging in a good light twenty feet away, then glasses will be of no avail, and it would only be a waste of money and time to try to fit them.

A third metal disk is called the "stenopaic slit," in which there is an adjustable bar which can be moved to widen or narrow the opening, as may be desired. This stenopaic slit is used in the detection and correction of astigmatism. The slit is placed in the trial-frame and rotated to the meridian of best vision, which is corrected by a spherical lens; it is then rotated at right angles, which meridian is also corrected by a spherical lens. The refraction of the two principal meridians is thus known, and the proper correcting cylindrical lens can be calculated therefrom.

UNMOUNTED LENSES UNDESIRABLE.

There are some trial cases sold in which the lenses are unmounted, and they are only mentioned to be condemned; their single advantage is that they can be sold for less money, but they cannot be called cheaper. The liability to soil them with the fingers, the difficulty to handle them easily and to place them in the trial-frame and remove them quickly, and the danger of chipping and breaking, as well as their incomplete appearance, make of them a very undesirable case. When the lenses are furnished mounted, they are burnished into metal rings—white metal being used for convex lenses and yellow metal for concave lenses, with the number of the lens stamped on the handle. In the cases of unmounted lenses the number is scratched on the lens itself, preceded by the plus (+) or minus (—) sign to indicate its refraction. Likewise prisms are marked (on the handle of ring) with the number of the prism in degrees. In the same manner cylindrical lenses are marked with the number of the lens, and, in addition, are marked to show the direction of the axis; besides which, in a great many cases, they are frosted or made opaque on either side of these marks and along the edges of the lens, this being done to show more quickly at a glance the direction of the axis, as the side sections of ground glass have straight borders parallel to the axis. The size of test-lenses (that is, the diameter from edge to edge of ring) is about one and one-half inches.

RINGS AND HANDLES FOR TEST-LENSES.

In some of the later and better test-cases the rings are different from those above described; instead of the lenses being burnished into rings, according to the old method, these rings can be opened and the lens placed in the groove and firmly secured by means of a small screw, which fastens them in the same manner as spectacle lenses are secured in spectacle frames. This is considered an advantage, as the lenses can be removed or replaced in case of breakage, or error in lens, without injury to either lens or ring, which cannot be so readily done when they are burnished in. These rings are made of steel and nickel-plated, and both convex and concave of the same color, but they are distinguished by the plus or minus mark being cut out of the handle. These nickel-plated rings will perhaps wear longer than the ordinary rings, of which some are gilt and some silvered.

Sometimes the cylindrical lenses in the trial-frames are furnished without handles, so that the axis can be the more readily rotated completely around the circle to any desired degree; but those which have the handle are preferable, because they can be more easily manipulated, and usually no difficulty is experienced in rotating them to the proper position, on account of the way they are set in the ring and the construction of the trial-frames that are used.

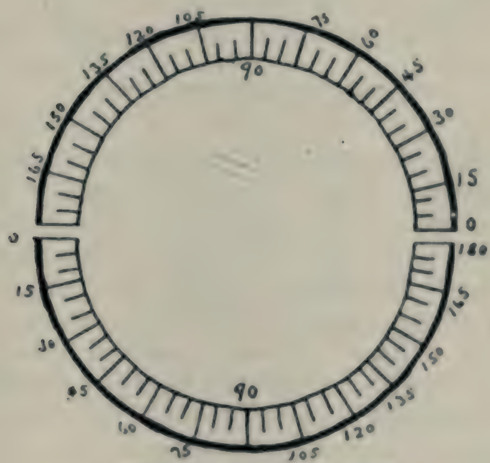
A trial-case of test-lenses is *the* greatest necessity of the optometrist, but the high price at which such cases have been sold (until recently, when they can be purchased much more reasonably) has acted as an obstacle in the way of the optometrist giving the attention to his business which it deserves. The effort on the part of manufacturers has been to furnish trial-cases as inexpensive as possible, in order that they might be within the reach of a much larger number of optometrists, and as a consequence a great variety of different cases have been advertised and placed on the market; but as the effort to cheapen the cases goes on, the efficiency of the case rapidly declines in proportion, until they are hardly of enough practical value to justify the outlay for them. A great many of the numbers are left out, and when one of these numbers is wanted it can only be obtained by combining two or three lenses together in the clip; and when using the dioptric system, combinations can be very easily made without any knowledge of mathematics whatever.

TRIAL FRAME.

The most important instrument contained in the test-case is the *trial-frame,* the use of which is to grasp the test-lenses firmly and hold them before the eye, and at the same time allow them to be readily changed. The simpler forms are not unlike heavy spectacle frames, with semi-circular or half-eyes, rounded to hold the circular lenses of the trial-set, and usually with straight temples, although hook temples may be substituted. The "eye" of the trial-frame (or, more literally, the half-eye) is made up of two or three grooves, in which as many lenses can rest; or, in place of the grooves, may be fitted with three hooks, at equidistant intervals, on both inside and outside of frame, which answer the same purpose of holding the lenses before the eyes. In frames like these, only spherical lenses are intended to be used; while for cylindrical lenses the face of the frame must be graduated around the semicircle in degrees, and in this the axis of the lens can be turned to any degree that is found necessary.

The rotation of the cylindrical lens is accomplished in many trial-frames by the movement of the lens, while in some of the more elaborate frames the outer lens-holder is movable, so that it can be rotated, and thereby the axis of the lens can be brought to any desired angle without any turning of the lens itself. The inner, or posterior, lens-holder is for spherical lenses, and remains stationary, not being affected by the revolution of the holder carrying the cylindrical lenses.

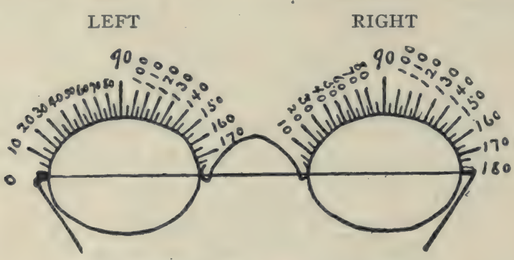
The graduations on cylindrical trial-frames are always the same—commencing at zero, at the patient's left, and proceeding upward to fifteen degrees, thirty degrees, and up to ninety degrees, which is exactly vertical, and down to one hundred and eighty degrees, which is exactly horizontal; and then commencing at this point, which is the patient's right, and going down to ninety degrees, which is vertical, and proceeding up to one hundred and eighty degrees, which is horizontal. It will be observed that the vertical meridian is always at ninety degrees, while the horizontal meridian may be either zero or one hundred and eighty degrees (in prescriptions it is usually written 180°, although sometimes the capital letter H is used to indicate the horizontal meridian); and it should be further noted that these figures refer to the frame as it sets on the patient's face and as seen by the optometrist standing in front of it. This is sometimes a difficult matter to understand (where to commence and where to end counting), and the following diagram is introduced in the hope of making it plainer:



Graduated Front of trial frame.

THE NUMBERING ON TRIAL FRAME.

Experience with optometrists leads to the belief that many of them do not have clear and definite knowledge of this matter: and it sometimes proves itself a bugbear even to those otherwise well informed. For instance, a number of years ago, one of the medical students attending the clinics at the Wills Eye Hospital (the most noted hospital of its kind in Philadelphia) asked the surgeon in charge, who was an eminent oculist, where the numbering commenced of the degrees used to denote the position of the axis of cylindrical lenses. The oculist replied on the right, then corrected himself, and said on the left, and seemed to be confused; and was really unable to give a definite reply to the question until he had called for a trial-frame and given the matter several moments' consideration. Of course, the ophthalmic surgeon of a large hospital gives more attention to, and takes more interest in, cases of disease—such as the various inflammations to which the eye is liable, and which require careful treatment—or



The graduation on prescription blanks.

cataract and cross-eyes, which call for the use of the knife, and which all afford an opportunity for the exhibition of the surgeon's skill and for the accomplishment of brilliant results; while refraction cases, which are tedious, and try the physician's patience, are left for the younger doctors to correct, and on whom they must gain their experience. But still, in spite of this, one would think an oculist of age and experience would have been able to answer this question without a moment's thought; and yet this little incident serves to show that this question may prove a source of confusion as well to the educated physician as to the less pretentious optometrist.

The principal source of confusion arises from the difference between the notation of the degrees as it appears on the front of the trial-frame and on the oculists' prescription blanks; and illustrations of both have been introduced here, so that the comparison can be readily made between them, and the source of error be removed.

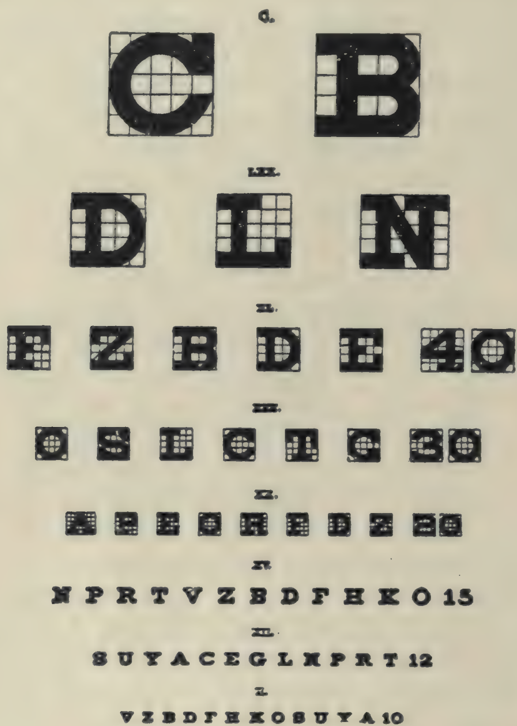
Repeating, then, what was said before, the notation always commences at zero, *at the patient's left and proceeds upward* to ninety degrees, and downward on the opposite side, or on the patient's right, to one hundred and eighty degrees, and thus completes the semi-circle. If the graduation is on the lower segment of the circle, it commences at the patient's right, and goes down to ninety degrees, and up to one hundred and eighty degrees at the patient's left. With this fact firmly fixed in the mind, a comparison between the two diagrams given above will show that there is really no conflict or difference between them, but that they are both graduated exactly as this rule directs. In the first illustration, the numbers are seen on the face of the trial-frame as they appear to the optometrist standing in front; while in the second diagram, the degrees are numbered as they would appear to the eyes of the wearer looking at the posterior surface of the glasses, if seen by him, and particularly as they would appear to the manufacturing optician as he grinds the lenses into the frame, because he works from the posterior surface. A thorough understanding of this subject by the optometrist now will save him much annoyance and confusion in the future.

A great many styles and varieties of trial-frames have been placed on the market by the various manufacturing optical houses, each of which is claimed to be the best. The points to be desired in a trial-frame, in order that it may meet every requirement, are grooves for two lenses, the front of which is to be graduated in degrees for cylinders; movable lens-holders, so that they may be adjusted to the distance between the eyes to be tested; a movable nose-piece that may be adjusted to hold the lenses at the proper height before the eyes; the whole to be made of some material that will not be too heavy.

COMPLETE SET OF TEST-TYPES.

4. A complete set of test-types is the next requisite in the outfit needed by the optometrist, which will include test-letters for distant vision, test-types for near vision, and astigmatic cards of radiating lines and letters.

The card of test-letters used for testing distant vision is made up of block-letters, the strokes and limbs of which are solid black, with parallel edges, their width being exactly one-fifth the height of the letter, and the width and height being the same, and printed on heavy card-board in a manner convenient for hanging on the wall. A practical point is to have two or three of these cards, with the letters arranged differently in order, as a patient whose eyes are examined more than once soon becomes familiar with the letters on one card, and might be able to repeat them from mem-



Test letters for Distant Vision.

ory, and thus unknowingly mislead the optometrist, who could not know whether the letters were repeated from sight or from memory.

In order that the image formed on the retina may be of sufficient size to excite perception, the object which produces the image must be seen under a certain visual angle. Now the smallest retinal image which can be perceived at the yellow spot of the retina corresponds to a visual angle of one minute (1′), so that if two points were separated by an interval of less than one minute, the eye would be incapable of perceiving the separation between them, and they would produce upon the eye the effect of but a single point. The visual angle (it may be remarked) is the angle included between two lines drawn from the top and bottom of the object which converge to and cross each other at the nodal point of the eye, which is situated just back of the crystalline lens.

These principles were made use of in the construction of the test-letters which are used for determining the acuteness of vision, the letters being drawn so that each limb and sub-division and space would subtend an angle of one minute at the nodal point, while the height and width of the letter would be five times the width of the limbs, causing the letters as a whole to subtend an angle of five minutes at the same nodal point.

In other words (referring to the visibility of the test-letters used for distant vision), the width of the lines of the letter forms on the retina two points, just barely far enough separated to be distinguishable as two points, while the five lines or spaces which make up the size of each letter will then form an image on the retina, which, in the majority of cases, will be the smallest which the normal retina can appreciate.

SNELLEN'S TEST-LETTERS.

The test-letters of Snellen, which are constructed on these principles, are those in most common use. They are drawn in the proportions mentioned, and in different sizes, each of which is marked with a number, which indicates the distance in feet at which the letter should be distinctly seen, and at which the height and width of the letter will be seen under a visual angle of five minutes, and the limbs of the letter at an angle of one minute. The top row of letters should be distinctly legible at two hundred feet; the next at seventy feet; the next at forty feet; and so on to the smallest, the letters of which can be named at ten feet; and it should be remembered that the angle produced by the large letters at two hundred feet and that produced by each of the letters at their respective distances is exactly the same as that caused by the smallest letters at ten feet.

It is maintained by Snellen that in order to be able to distinguish one letter from another the eye must be able to notice the width of the lines which make the letter, and also the spaces between the lines; and as it is desired to make this test as delicate as possible, the width of the lines and the spaces between them are drawn so as to correspond to a visual angle of one minute, which is the smallest space which the retina is capable of perceiving. This applies to a great many of the letters, as, for instance, to differentiate between **C** and **G** and **O,** where the eye must be able to distinguish the white space which interrupts the circle in **C** and **G,** and must also be able to notice the addition to **G** which **C** lacks. This same is true of **E** and **F,** where the eye must be able to make out the additional line at the bottom of the **E,** and likewise between **B** and **H,** which appear similar in shape at a distance, and require to be really seen before they can be differentiated.

POSITION OF TEST-CARD.

The test-card for distant vision should be hung on the wall in such a position as to be illuminated by a good light, and far enough away from the patient to avoid the necessity for any effort of accommodation. Only parallel rays are focused on the retina of the emmetropic eye without the aid of the accommodation; and only those rays are absolutely parallel which proceed from objects at infinite distance. But for the practical purposes of the examiner in testing distant vision, twenty feet has been by common consent agreed upon as the standard distance at which the best results can be attained in such examinations; and every optometrist is advised and urged to test his cases at this distance, if the size of his store or office will permit. Rays of light proceeding from an object at twenty feet may be assumed to be parallel, and are so near parallel as not to disturb the calculation. Oftentimes this distance cannot be secured, and the examination must be made at fifteen feet, or twelve feet, and sometimes even at ten feet; and while satisfactory results may be attained at these distances, it should always be remembered that with every approach to the eye there is some effort of the accommodation called for, however slight.

Snellen's test-letters are those in most common use, and they seem to be suited for all practical purposes, and to yield satisfactory results. At the same time, it is well to know that there are other test-types in use in different countries, but the only ones which seem to have any value comparable with those of Snellen are those of Green and Monoyer; which latter, however, we will not take the space to describe, as Snellen's will be the only ones which our readers will be likely to use.

It is not unusual to meet with patients, especially in the young, where the acuteness of vision is better than the standard described above. A card of letters has been constructed which subtend an angle of four minutes instead, and which often proves useful.

The usual cards are white or cream colored with black letters. Some time since black cards were introduced, the letters on which were white. The argument used is that it is the white that stimulates the retina instead of the black, and hence in this case it is the letters and not the card that produces the retinal stimulation. The black card does away with the glare produced by the white card, and hence is more soothing to the eye under examination, and besides, the white letters seem to stand out from the card with clear-cut edges.

For the use of young children there should be a picture chart of test objects, which is drawn up to the usual angle of five minutes for the whole object, although it is possible to make the component parts of the object subtend the one-minute angle.

It is well to have several cards with different letters or the letters in different order, as patients without intention soon have them memorized and the test loses much of its value.

READING CARDS.

The test-types for near vision are usually selections of reading-matter of different sizes, each of which is marked with the distance at which it should be seen by a normal eye with good sight. Smaller block-letters, graded on the same scale as Snellen's distant letters, are sometimes used, but those most commonly preferred are Jaeger's, because his letters are of the ordinary shapes, although they have the disadvantage that they are not arranged on any scientific plan, but are simply printers' types of various sizes.

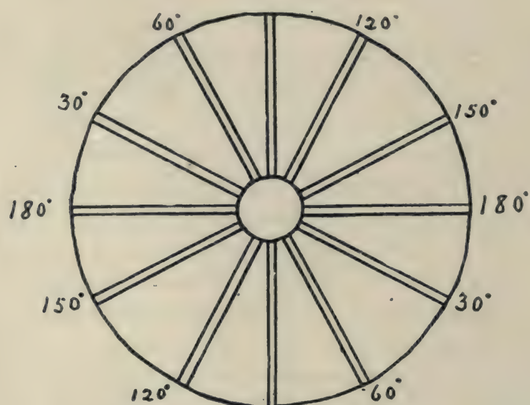
The value of selections of reading-matter as a test is very much impaired by the fact that persons who are accustomed to reading are able to guess at the majority of words by their general appearance and their relation to neighboring words, while illiterate and uneducated persons must decipher the letters one by one, which places the latter in a more unfavorable position than the former, and therefore vitiates, to some extent, the value of the test as not being a certain proof of visual acuteness. This is sometimes remedied by the use of words intentionally misspelled (Josh Billings' style); but for an accurate test, isolated letters should be used, constructed on the same principle as the larger test-types.

ILLITERATE CARDS.

Occasionally the optometrist meets with a customer who cannot read, and sometimes he is called upon to examine the eyes of young children who do not know their letters. Examinations of such persons are always more or less unsatisfactory, and the desire should be to make them as nearly accurate as possible. For use in such cases, cards of numbers are printed in various and increasing sizes; but what is more preferable (and is even necessary for those who cannot tell the numbers) is a card of figures with projecting arms like a capital letter **E.** These are printed in the same sizes as the letters on the ordinary test-card, and with the arms pointing up and down, to the right and to the left. The test of the patients' ability to see these figures is determined by their ability to tell in which direction the arms point.

ASTIGMATIC CARDS.

The optometrist's selection of test-types will embrace several cards for the determination of the existence or non-existence of



Radiating lines for astigmatic test.

astigmatism. Those in most common use are the radiating lines, somewhat similar to the face of a clock (to which it is oftentimes compared); and Dr. Pray's series of astigmatic letters, which are made of black lines and white spaces, the lines and spaces running at the same angle in each letter, and every letter representing a different angle. The full card is composed of twelve letters, which are drawn at the following angles: 15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°, 135°, 150°, 165°, and 180°.

Attention should be given to the numbering of the angles, and comparison made between the above figures and those on a preceding page representing the graduated front of trial-frame and the graduations on the prescription blanks. In this way the

Dr. Pray's astigmatic letters.

examiner will have clearly fixed in his mind the method of numbering the degrees on the astigmatic semi-circle, which is (and it is repeated again, that it may become indelibly fixed in the memory) to commence at the patient's left and complete the semi-circle, or the 180°, at the patient's right.

MEASURING-STICK, OR METRIC-RULE.

5. This is used to measure the range of accommodation and to determine the near-point and far-point, and in the absence of a short rule may be used to measure the pupillary distance. An ordinary yardstick will answer the purpose, but the optometrist is advised to procure, as more preferable, a metric measure, which is exactly one meter long, and is marked on one side in centimeters and millimeters, and on the other side in inches and fractions of inches.

RECORD-BOOK, OR CASE-BOOK.

6. Method and system are of advantage in the conduct of any business, but they are especially invaluable to the optometrist, who must keep a methodical and systematic record of his cases if he wishes to do business with pleasure and profit to himself as well as to his customers. No man who does business in a slipshod, careless way can succeed, and he doesn't even merit success;

while the careful, systematic man achieves success because he deserves it.

No optometrist should sell a pair of glasses without making a record of the sale. It will take but a moment's time to write down the date, the name of the customer, and the number of the glasses sold, with, perhaps, the style of frame and the price paid. But some one will say that it does not pay to go to so much trouble with a pair of twenty-five-cent glasses, and with this statement I cannot disagree. But here is a broader and stronger statement, which undoubtedly will strike a responsive chord in every optometrist's breast—*don't sell such cheap glasses that you cannot afford to take the time to fit them and make a record of them.*

When a customer asks for a pair of cheap glasses, a handful of various numbers is laid on the counter, and he is told to help himself; he picks out a pair with which he thinks he can see, and pays his money, just as if he was buying a shirt collar, and without the advice or responsibility of the optometrist. This is certainly wrong—it is hurtful for both optometrist and customer; the glasses may damage the patient's eyes and the optometrist's reputation at the same time. This is not the place to make a more elaborate argument in this direction, as the matter is only mentioned incidentally in support of the statement that every optometrist should keep a record of the glasses he has fitted, but I have a very positive opinion on this subject that it does not pay the optometrist to keep and sell cheap glasses; it does not pay either optometrist or patient; but if the latter will insist on risking his eyes with such trash, then let the optometrist wash his hands of responsibility and permit his customer to go elsewhere to buy them.

The case-book or record-book, therefore, is considered as a necessary part of the outfit of every optometrist.

These record-books may be divided into two classes—those which are designed to keep a simple record of the glasses sold, and those which are intended to preserve a complete record of the examination of the vision as well as of the glasses prescribed.

The first or simplest class of record-books can be used as a register for glasses sold for simple presbyopia, and for all simple glasses that are fitted without any very extended or elaborate examination. The book can be ruled or spaced for the following headings: Date, Name of Customer, Number of Glasses, Style of Frame, Price. Any ordinary blank book can be purchased and ruled as above by the optometrist himself, or the books can be ordered ready-ruled. An index should accompany the book, and if the name is entered in the index at once it consumes but little time and makes but little trouble; while if the names are allowed to accumulate, the indexing becomes a tedious task and is apt to be neglected. This destroys the value of the record-book, as its usefulness depends on the ability to find a given name and find it quickly, which can only be done by the aid of an index. The optometrist should take pride in keeping this book neatly and carefully, and it will be a source of satisfaction to him as his optical business grows and his customers return, and he desires to look up the glasses previously sold to them.

The second class of record-books should be much more complete and elaborate, so that they will not include the simple record as above, but will contain a complete record of acuteness of vision, range of accommodation, and all the points revealed by a careful examination of the eyes. Such a book should embrace the following headings:

No.
Date.
Name.
Age.
Residence.
Occupation.
History of Case.
Present Condition.
Symptoms Complained of.
Ever Worn Glasses?
If So, What Number and How Long?
Any Other Remarks.
Vision. R. E. L. E.
Refraction. R. E. L. E.
Accommodation. N. P. F. P.
With —— N. P. F. P.
Insufficiency of Muscles.
Astigmatism.
Distance. R. E.
" L. E.
Reading. R. E.
" L. E.

Ophthalmometer.
R. E.
L. E.
Retinoscope.
R. E.
L. E.
Ophthalmoscopic Appearance.
R. E.
L. E.
Diagnosis.
Suggestions.
Report of Case
Frame.
Pupillary Distance.
Height of Bridge.
Inclination of Bridge.
Size Eye.
Width Base.
Width Temples.
Length Temples.
Distance. R. E.
" L. E.
Constant. R. E.
" L. E.
Reading. R. E.
" L. E.

Such a book also serves to suggest the different steps that should be followed in making a complete examination of the vision, and is really indispensable to the thorough optometrist. A record-book, such as is described above, which was specially compiled for the use of the optometrist, and is at the same time complete and simple of arrangement, can be had at THE KEYSTONE office for the sum of two dollars. This book has an index, an indispensable portion of every serviceable record-book. Some of the more systematic optometrists keep a separate index book, in which they enter the names of all customers from both the above-mentioned classes of record-books.

OPHTHALMOSCOPE.

7. The ophthalmoscope, which was formerly looked upon as an instrument for use by the medical faculty alone, has now a place in the outfit of every well-equipped optometrist. It is not unusual, however, to find among the less experienced optometrists an exaggerated and erroneous impression as to the purposes for which an ophthalmoscope should be used, and the information that can be derived from its employment. Some of these optometrists entertain such an exalted opinion of this instrument, that it appears as if they must be under the impression that when they look into an eye with the ophthalmoscope, they will be able to see stamped in the eye, in plain figures, the number of the glass required to correct that particular case. In fact, the ophthalmoscope is looked on by some optical students and optometrists as a magical and mystical instrument with a mysterious something about it which makes it difficult to understand its use, but which, when comprehended, affords them an infallible method for fitting the most difficult cases, to the exclusion of

every other means. Riper experience brushes away these pleasing delusions and strips the ophthalmoscope of much of its importance in the hands of optometrists, who are interested only in correcting optical defects. In the case of physicians it is very different; as, in the treatment of diseases of the interior of the organs of vision, the ophthalmoscope becomes a necessity, to note the advance of disease and watch the effect of treatment. Besides which, the value and usefulness of this instrument are in direct proportion to the skill of the operator.

In using the ophthalmoscope to diagnose errors of refraction, the physician or optometrist examines the fundus of his patient's eye. If his own eye and the patient's eye are both normal, a perfect image of the optic disk and the retinal vessels can be obtained; but if any ametropia exists in either physician's or patient's eye, the ophthalmoscopic picture will be to that extent marred, and the lens required to afford a perfect view of the fundus will be the measure of the ametropia. In these cases it is absolutely necessary that the observer know his own refraction, and that if any ametropia be present it be corrected by the proper lenses, after which he is in a position to examine the fundus of his patient's eye and ascertain the number of the neutralizing lens required to afford a perfect image of it. Under the most favorable circumstances and with the greatest dexterity on the part of the observer, this affords but an approximate correction; and hence it can be laid down as a broad, general rule, that *no error of refraction can be accurately and satisfactorily measured or corrected by the ophthalmoscope alone;* but the use of test-letters and test-lenses is by far the most reliable (as it is the most used) method of measuring and correcting these refractive errors, reserving the ophthalmoscope to verify the results thus obtained.

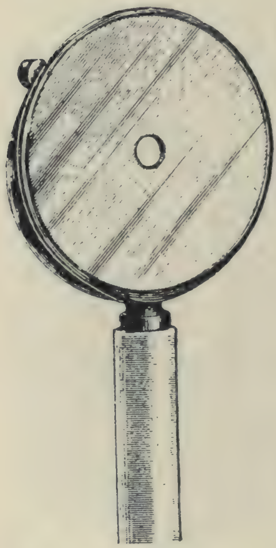
In this connection the use of the retinoscope may be mentioned, or in other words, "the shadow test." This is a procedure only brought into use of late years. The use of the ophthalmoscope and retinoscope in the diagnosis and correction of refractive errors will be fully and thoroughly explained and demonstrated later on.

RETINOSCOPE.

8. The more complete trial-cases usually contain one of these instruments, the use of which is at present attracting the attention and engaging the interest of all progressive optometrists.

Retinoscopy, or keratoscopy, or pupilloscopy, or skiascopy, or the shadow-test, as it has been variously termed, is a valuable auxiliary method for determining the refraction of the eye, and it is one which the optometrist cannot afford to neglect. It is especially useful in the examination of children or of uneducated persons.

This method of determining the refraction depends upon the direction of the movements, in the pupil, of the shadows cast by the fundus reflexes, when light is reflected into the eye by the retinoscopic mirror, which is then rotated vertically or horizontally.



These movements are different in the several refractive errors, being dependent on the condition of the emergent rays, those from an emmetropic eye being parallel, from an hypermetropic eye divergent, and from a myopic eye convergent.

The room should be darkened and the patient placed directly under the light. The optometrist is seated at a distance of one meter, and reflects the light directly into the eye, which produces the red reflex in the pupil. The mirror is then rotated and a movement of the red reflex in the pupil is caused, which is followed by an area of shadow.

If the mirror of the retinoscope be plane (which is preferable), the movement of the shadow will be in the same direction as the tilting of the mirror, if the case be one of emmetropia or hypermetropia. While the shadow produced will travel in the opposite direction from the way the mirror is tilted, if the case be one of myopia.

The Principle of Retinoscopy is to find the *point of reversal* by means of lenses placed in front of the eye, and it is the chief objective method of determining the condition of refraction.

The *Reflex* seen in the patient's pupil is subject to many variations from different causes. In high errors the reflex is dull; in low errors, bright. Hence in ametropic eyes the reflex grows brighter as the correcting lenses are placed before the eyes. In high errors the movements of the reflex are slow, and in low errors, fast.

The rule for the selection of lenses is to use a convex lens when the movement is with, and a concave lens when the movement is against.

The parallel rays that emerge from an *emmetropic* eye will not focus in the observer's eye but will cause a *with* movement. A + 1 D. lens placed in front of such eye will cause these parallel rays to converge to a focus on the observer's retina one meter away and will check all movement of the reflex. Hence we are able to recognize emmetropia by the fact that a + 1 D. lens neutralizes the movement, and for this reason we must make an allowance of this amount in all errors of refraction.

The divergent rays that emerge from an *hypermetropic* eye will not focus on the observer's retina but will again cause a *with* movement. Convex lenses of increasing strength are used until the point of reversal is reached and the movements neutralized. Then 1 D. must be deducted to allow for this amount, which is needed in emmetropia. As an illustration, if + 3 D. is required to establish the point of reversal at one meter, then after making the proper deduction + 2 D. would represent the correction at infinity.

The convergent rays that emerge from a *myopic* eye come to a focus before reaching the observer's eye and will cause an *against* movement. The optometrist may approach his patient until he reaches the point of reversal, and then the distance from the eye will show the amount of myopia. Or he can use concave lenses until he neutralizes the movement. Then 1 D. must be added to allow for the distance at which the test is made.

In a few words, then, the rule is as follows: Add — 1 D. to the retinoscopic finding, whatever that may be.

In *astigmatism* the two principal meridians are to be measured, first the meridian of least error and then the meridian of greatest error, from which it is a simple matter to figure out the formula required after making the proper allowance of — 1 D.

LUMINOUS INSTRUMENTS.

In recent years the luminous ophthalmoscope and luminous retinoscope have been introduced. They contain an electric light of small candle power, the light from which passes through a strong convex lens and falls upon the mirror, from which it is reflected into patient's eye. These self-luminous instruments have numerous advantages: no heat, as from gas, light always in position and moves with every movement of instrument; can be used in any position, even when patient is reclining; the brilliancy of illumination can be increased or diminished by a rheostat; freedom from reflections and glare, etc.

THE PRISOPTOMETER.

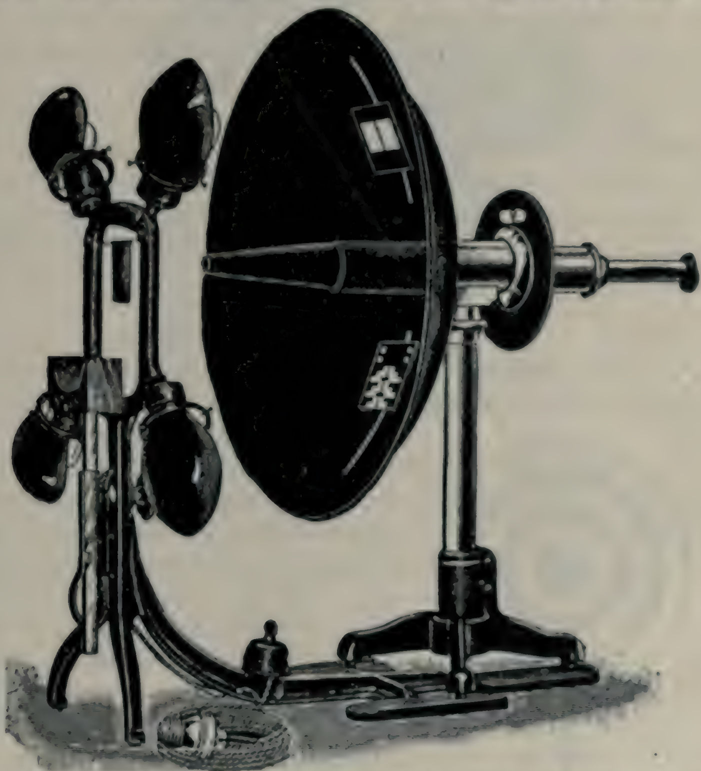
9. The prisoptometer is an excellent instrument for the detection and correction of the various refractive errors. It consists essentially of a double prism, which can be revolved from 0 to 180°. As the patient looks through the circular opening in the center of the instrument, at the white object circle, he will see two objects, and the relation they bear to each other will indicate whether the case be emmetropic or ametropic, and also point out the nature of the ametropia.

If the white circles are simply in contact, the case is one of emmetropia. If the circles overlap each other, the case is one of myopia, and the concave lens that separates them to mere contact will be the measure of the myopia. If the circles are separated from each other, the case is one of hypermetropia, and the convex lens that restores them to mere contact will indicate the amount of the hypermetropia.

The revolving of the prism will cause a revolution of the circles, and if they maintain the same relative position all the way around the eye is spherical in shape, or, in other words, there is no astigmatism; whereas, if astigmatism is present, the circles will separate or overlap at some one point, thus indicating either hypermetropic or myopic astigmatism, which is then corrected by a convex or a concave cylinder, with its axis at right angles to this point.

OPHTHALMOMETER.

10. This instrument is invaluable in measuring the curvatures of the cornea, and in estimating the degree and kind of



astigmatism. Its scope is limited to this defect, and it is of no use in determining the refraction; but in spite of this, the information which it conveys is so direct and positive, that it is conceded to be an instrument of such inestimable value as to justify the progressive optometrist in making so expensive an addition to his outfit.

Of late years there has been considerable discussion as to the value of the ophthalmometer, largely because there has not been the proper appreciation of the purport of the instrument, as well as its limitations; and the statement cannot be made too emphatic that its use is limited to the measurement of the corneal curves on which the existence of astigmatism mainly depends, and that it is of no value in determining either myopia or hypermetropia, which are due entirely to the lengthened or shortened axis of the eyeball. The detection and correction of astigmatism being the most difficult part of the optometrist's work, and the ophthalmometer being the most reliable instrument at his command for this purpose, the controversy as to its scope and value is much simplified.

The principle on which the examination by the ophthalmometer is based is the measurement of the curvatures of the cornea by means of reflected images viewed through a telescope, the idea being not so much to ascertain the absolute curvature of the cornea, as to detect the differences of curvature in its different meridians.

THE KERATOSCOPE, OR KERATOMETER.

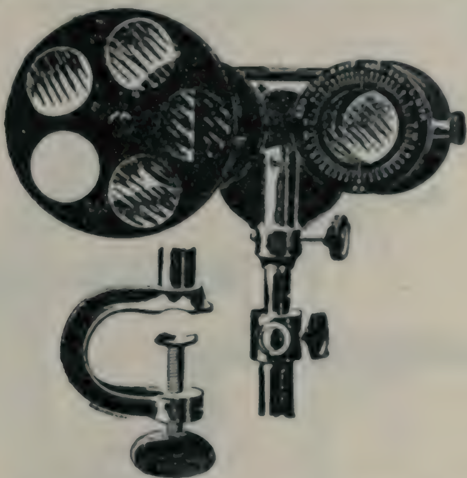
11. The purpose of this instrument is also to measure the cornea, to detect any irregularities of its surface, and to determine the existence of astigmatism. It is very simple in its construction, and depends upon the manner in which the cornea reflects these concentric rings. If the cornea has the normal spherical curvature, these rings will appear circular; whereas, if any marked degree of astigmatism is present, these rings will appear oval, and the direction of their longest diameter will indicate the defective meridian.

THE PHOROMETER.

12. The condition of the ocular muscles is an important feature in the examination of almost every case that applies to the optometrist, and this can be best determined by the use of a phorometer, which enables the tests to be made quickly and accurately. By means of this instrument the optometrist is

able not only to measure the muscular equilibrium and detect any departure from the normal condition, but at the same time and with equal facility to ascertain the strength and position of the correcting prisms.

This is scarcely the place to urge upon the optometrist the necessity of an examination of the muscular system of the eye, as a



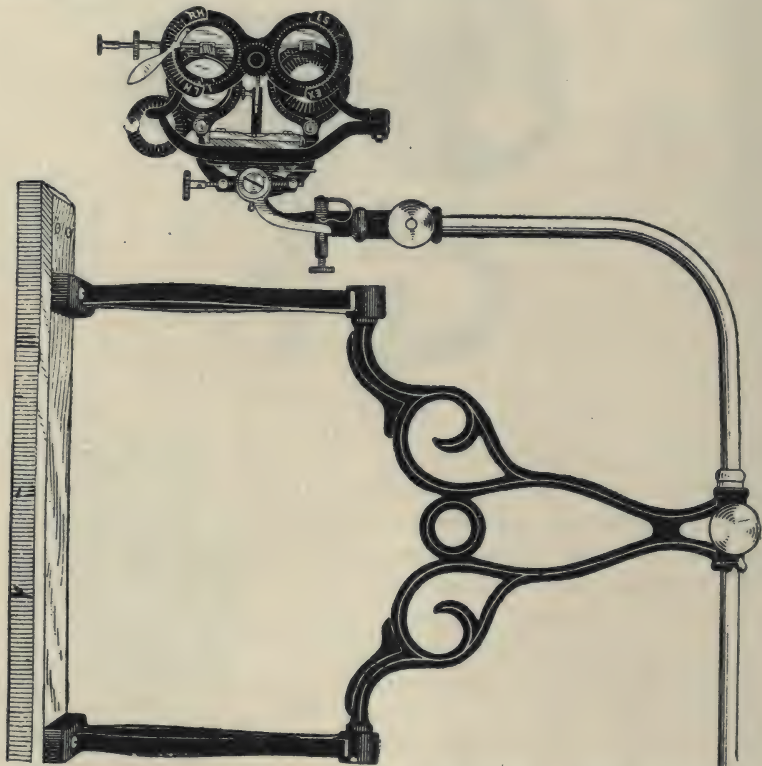
routine practice in every case of any magnitude that applies for correction. And while the condition of the muscles and the existence of any insufficiency can be determined by the Maddox lenses or even by simple prisms, yet the advantages of a phorometer are self-evident.

AN ADJUSTABLE OPTICAL BRACKET.

13. There has always been more or less objection on the part of the patient to the use of the trial-frame, which is complained of as being heavy and uncomfortable, the pressure on the nose being unbearable if the examination is protracted, while the optometrist finds it troublesome to adjust to the patient's face and difficult to keep in place. To meet these objections an adjustable bracket with a test-lens holder, which can be firmly attached to the wall, the window sill, or the back of a heavy chair, has been devised by Dr. Charles A. Oliver.

In connection with the test-lens holder and its use in measuring the refraction of the eye with trial-lenses, it also contains a phorometer; and the advantages of having this instrument in a convenient form for quickly placing in front of the eye, and in a more rigid position than is possible with a stand or tripod, are obvious.

In addition there is a Risley rotary prism, which can be swung in front of the right eye, and a Maddox rod, which can be swung in front of the left eye, and removed to the side when not in use.

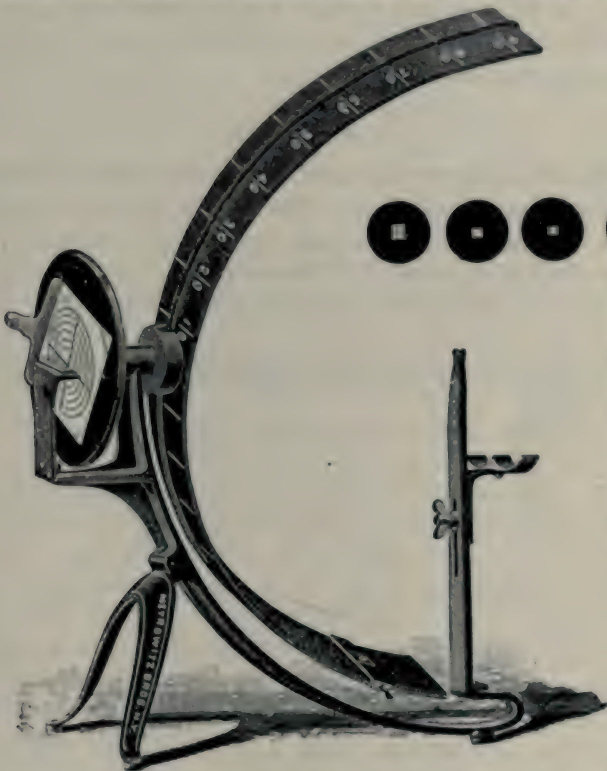


This bracket, by a number of adjustments, can be placed in any position desired, has an adjustable pupillary device by which the centers can be regulated, a scale to denote the pupillary distance, and also a spirit-level to insure perfect accuracy.

PERIMETER.

14. A perimeter has been included in the optometrist's outfit, but it is not urged as an actual necessity. It is an instrument

rather for the use of the physician than the optometrist, although the latter can also profit by the information gained by its use. It has been devised for testing the field of vision, to ascertain its extent and to detect the existence of any blind spots. It, there-



fore, has nothing to do with *direct* vision, or with the vision of the yellow spot, or with the vision that can be corrected with glasses; but deals only with *indirect* vision, or the vision of the retina outside of the yellow spot. Detailed directions for its use will be given at another place in this work.

OPHTHALMIC CABINET.

15. Various styles of cabinets have, in recent years, been placed on the market, their object being to form a convenient receptacle for holding the test-cards, preserving them from dust and injury, and allowing them to be placed before the eyes as desired. All the cards are out of sight except the one in use.

Some of them present an astigmatic clock-face dial, which can be rotated and thus afford a convenient method of determining the location of the defective meridian in astigmatism and the position of the axis of the correcting cylinder.

Some of the cabinets contain electric attachments for the illumination of the test-cards, which light can also be used as a test for muscular insufficiency.

A LENS MEASURE.

16. The lens measure shows the curvatures of the surfaces of the lens as expressed in dioptres. The measure is rotated over the surfaces of the lens, and if the indicator does not change its position the surface is spherical; if it moves the surface is cylindrical, and the axis of the cylinder is located where the hand points to zero.

A lens measure is really an indispensable item in the outfit of the optometrist.

CHAPTER X.

METHOD OF EXAMINATION.

We have now passed through the theoretical portion of our subject, and this brings us to the practical part. The foregoing chapters have been devoted to theory (so-called), while the remaining chapters will treat of practice; or, in other words, the balance of the work will show how to put into practical use what was learned in the former chapters. We have treated, with considerable attention to detail, the theoretical subjects embraced in this treatise. To many optometrists these matters may have seemed dry and uninteresting, and perhaps some may have even thought them unimportant; but they are the necessary foundation, deeply and securely laid, without which the lasting superstructure of a successful optometrist cannot be builded. That is to say (and the statement cannot be made too strong), no optometrist can make a reputation for himself and build up a growing optical business, unless he is grounded in the scientific principles of his profession. Otherwise, where is he better than the country storekeeper who sells glasses, or the itinerant peddler? Otherwise, why should he claim the title of "optometrist"? An optometrist is really a person skilled in the science of optics, and this is the original meaning of the word; but in later years the significance of the word has been changed, and the title assumed by any dealer who keeps for sale a stock of spectacles and eyeglasses, however small. This should not be; only those persons should be called optometrists who have had special training and acquired special knowledge and skill, and no reader of this work should content himself until he has measured up to this standard.

METROLOGY OF THE EYE.

The science of the examination of the eye in a healthy and diseased condition is of recent growth. It might be called the "metrology" of the eye, which literally means a discourse on the measurement of the eye. It is only within the past fifty years that the physician was able to ascertain much more than the simple fact of perfect vision, or impaired vision, or no vision at all. In the latter class, two grand divisions were included under the names of amaurosis and amblyopia, which Landolt says were differentiated as follows: "In amblyopia the patient saw nothing, but the physician saw something; in amaurosis, neither the physician nor patient saw anything." That is to say, the word amblyopia was used to include all those visual defects which were produced by changes visible to the eye of the physician, such as opacities of the cornea, etc.; while, on the other hand, all those diseases which had their origin and seat in the interior of the eye, such as retinitis, choroiditis, atrophy of the optic nerve, etc., and which were not appreciable to the unaided eye of the physician, were included under the general head of amaurosis.

HISTORY OF EYE EXAMINATIONS.

The first important work in the line of the examination of the organ of vision was accomplished by an Englishman by the name of Thomas Young, who published the results of his studies in the "Philosophical Transactions," in 1793. He seems to have been a man of unusual learning for his day, and his views were so much in advance of his time that they were neither understood nor believed by the scientific men of that period. It is an interesting fact that this same man was affected with a considerable degree of astigmatism, which he studied and corrected—this being the first case of the kind ever analyzed or corrected.

After this, many scientific men labored in the same field and worked along the same lines, one by one adding little by little to the stores of scientific ophthalmology, increasing and perfecting the means of examining the eye, evolving the laws governing the functions of refraction and accommodation, and making practical application of them in the detection and correction of the various optical defects with which they had to deal. This brings us down to Snellen, who devised his classical test-types, which really formed the first scientific method for the determination of the acuteness of vision. Then followed the introduction of color perception, the addition of which makes our means of examination of the visual apparatus very satisfactory and quite complete.

OBJECTIVE AND SUBJECTIVE METHODS OF EXAMINATION.

In the examination of the eyes, as in any other scientific undertaking, we should follow some definite plan and conduct our examinations in a systematic manner. This is absolutely necessary in order that nothing may be overlooked, and that we may accomplish our purpose with a reasonable certainty.

Physicians divide their examination of any portion of the body into *objective* and *subjective*, and we shall observe the same division in our examination of the eye. The object of the objective method of examination is to reveal the condition of the eye in a state of rest, while the subjective method is designed to make us acquainted with the eye in a state of functional activity—that is, to determine the condition of the function of vision. These two terms are used one opposed to the other, and it is important that the reader have a clear understanding of them.

According to the dictionary, the term *subjective* is applied to those internal states of thought or feeling of which the mind is the *subject;* opposed to *objective*, which is applied to things considered as separate from the mind and as *objects* of its attention. Thus *subjective* truth is that which is verified by consciousness; *objective* truth, that which results from the nature and relations of things. A *subjective* motive is an internal feeling or propensity; an *objective* motive is something external to the mind.

Applying these conditions to the examination of the eyes, a *subjective* examination is one which can only be made with the assistance of the patient, and depends on the information elicited by the patient's answers. An *objective* examination can be made without the patient's co-operation, without asking him a single question, and even against his own wishes, as it depends on the information which the observer is able to gain from an external examination of the conditions present, and which are visible or appreciable to his educated senses. A *subjective* examination reveals information which must come from the mind of the *subject*, while an objective examination reveals such conditions as are *objects* of the observer's attention. No examination is complete unless it is both subjective and objective.

OBJECTIVE EXAMINATION.

The objective examination usually comes first, and begins with a general inspection, which is accomplished at a glance, of the appearance of the head, and face, and eyes of the patient. Now the shape of the head and face and the form of the eye sometimes indicate the condition of refraction present. Hypermetropia is due to a want of development or an arrested development of the eye in length; while myopia, on the contrary, depends on an over-development or an elongation of the eyeball in its antero-posterior diameter. This difference in the form of the eyeball is sometimes accompanied by changes in the shape of the head and face, and indicated by the appearance of the features of the patient; a flat face indicating hypermetropia, and a full face and prominent eyeballs indicating myopia.

A lack of symmetry in the two sides of the face, one side being more prominent than the other, would point to the possible existence of anisometropia, a condition in which there is a difference in the refraction, one eye being myopic and the other hypermetropic. Other forms of asymmetry of the face, such as a deviation in the median line and a lateral curvature of the nose, often occur in persons who are astigmatic as well as anisometropic.

The appearance of the two eyes should then be compared for the purpose of noting whether there is any difference between them, and for the purpose of detecting any slight divergence or convergence of one eye, or any inequality in the size or dilatation of the two pupils, or any protrusion of one eye more than the other, or any drooping of either eyelid. A difference in the size of the opening of the lids can be readily recognized in this way.

A careful glance at the edges of the lids comes next, to determine the existence of any swelling or inflammation, and also to note the position of the lashes, which is a very important matter as regards the welfare of the eye and the transparency of the cornea. Displaced eyelashes, or lashes with their point directed toward the eyeball and scraping over the sensitive surface of the cornea, will set up and keep up a condition of irritation and inflammation that will neutralize the benefits to be derived from the most carefully adjusted glasses. And again, it should be remembered that an inflammation and swelling of the lids may be due to the strain caused by an uncorrected optical defect, and be speedily cured by the proper glasses.

INTERPUPILLARY DISTANCE.

The distance between the two eyes is a matter that should not escape the attention of the careful observer, because of the disturbing effect it may have on the act of convergence. It is a self-evident fact that in converging the eyes for vision at any given distance, the more widely the eyes are separated the greater must be the effort at convergence; while the closer the eyes are placed together the less convergence will be called for. In this way, in a certain number of persons fixing the eyes for vision at a given distance, there will be a great variation in the angle of convergence that is required for each person. As convergence is an act that is being constantly brought into play, it can easily be seen that any increase in the effort required (however slight) may be the source of great discomfort, and the overlooked cause of many cases of asthenopia. Prof. Landolt, the eminent French oculist, says: "For my part I am thoroughly convinced that the insufficiency of the internal recti muscles, which is such a frequent cause of asthenopia of myopic patients, is due in many cases to an excess of the distance between the two eyes."

This is a subject which is almost entirely overlooked, and yet it is one that deserves the most careful attention. It seems like a very simple matter to measure the distance between the eyes, and yet when we inquire into the question carefully, we will find that

to make an exact measurement is attended with no little difficulty. If we measure the distance between the centers of the pupils, as is commonly done, there may be two sources of error. In the first place, the pupil is not exactly in the center of the anterior part of the eyeball, but is a trifle to the inner side. This is an anatomical point that is not always borne in mind, as we are apt to take it for granted, as a matter of course, that the center of the pupil represents the center of the eyeball, and many optometrists have never known anything different. The second element of error lies in the difficulty of measuring the exact distance between the pupils, as this is a point that can only be determined approximately.

Another chance for error lies in the fact that the distance between the two eyes or between the pupils should represent the distance between the eyes when they are directed in lines parallel to each other; and here is where the difficulty lies, for it is almost a matter of impossibility for any patient to direct his eyes absolutely parallel; there always remains a greater or less degree of convergence, the amount of which cannot be determined. This objection is particularly applicable in cases of strabismus, where it is evident the eyes can never be brought to a state of parallelism, and yet these are the very cases where it is most desirable to measure the intra-ocular distance.

We have been considering the distance between the eyes with regard to its effect upon convergence and the relation it may bear in the causation of many cases of asthenopia, a matter too often overlooked. Of course, all optometrists are accustomed to make a simple approximative measurement when they want to determine the interpupillary distance, or the distance which should separate the glasses of spectacles, for which purpose an ordinary graduated rule may be satisfactorily employed. The patient is directed to look straight before him at some distant object, so as to make the axes of vision as nearly parallel as possible.

The measuring rule or yardstick is placed across the nose on a line with the center of the pupils, as close to the patient's eyes as possible, and in such a position that the end will be directly in front of the center of one pupil. The point of the rule that is directly in front of the center of the pupil of the other eye may be marked by the optometrist's thumb-nail, and the distance between these two points may be read off the rule, and the result will give the pupillary distance.

The optometrist should stand as far away from the patient's face when he makes this measurement as the length of his arm will permit, so as to diminish as much as possible the error that may be caused by the convergence of his own eyes. The optometrist's eyes will scarcely be more than two feet away from his patient's eyes, and the lines converging from his own eyes towards the patient's eyes will make the interpupillary distance a little less than the real distance. It has been calculated that the error in measuring the pupillary distance by this method is about one line (one-twelfth of an inch), which should be added to the apparent distance in order to obtain the correct measurement. While this method, if carefully employed, answers every purpose and its results are sufficiently satisfactory, yet a still greater degree of accuracy may be insured by adding about the sixteenth of an inch for distance and deducting the same amount for reading. For instance, if the distance on the scale was two and three-sixteenth inches, we would add one-sixteenth for distance, which would make two and four-sixteenth inches or two and one-quarter inches; for reading we would deduct one-sixteenth inch, which would leave two and two-sixteenth or two and one-eight inches. The optometrist will understand that this is done to make the optical centers of the lenses correspond to the pupillary distance, which varies with the increased and diminished convergence required in reading and distance.

Another method of securing accuracy and of obviating the error that may be caused by the convergence of both patient's and examiner's eyes, is to measure with each eye separately as follows: The optometrist is seated directly in front of the patient, who is asked to fix his eyes on some distant object which will give them an essentially parallel direction. The rule is then applied across

For measuring pupillary distance.

the patient's nose as before, with its end directly in front of the center of the pupil of the right eye, the exact position of which is determined by the optometrist's left eye alone, his right eye being closed. Then the optometrist's left eye is closed and the right eye is opened in order to read off the point on the rule which is exactly opposite the center of the pupil of the patient's left eye. This method requires that during the examination the optometrist should keep his head and eyes absolutely motionless.

Pupilometers are special instruments designed for measuring the interpupillary distance. There are different forms on the market, but they are all made on the same principle, and consist essentially of projecting points, one or both of which slide on a scale, and can be placed at any desired distance apart, one in front of the center of each pupil, while the distance between them is read off the scale on the instrument. To rectify the result obtained by one of these instruments, the same correction must be made as when a simple graduated rule is used.

In his own practice the author uses a pair of test-lenses marked as on page 233. It is simply a test-lens holder containing a plane lens, with two lines marked across its surface, the intersection of the two lines corresponding exactly to the geometrical center of the lens. These lenses are placed in the trial-frame, and the pupillary distance of the frame increased or diminished by turning the screw for that purpose until the intersection of the lines is directly over the center of each pupil, when the distance can be read off the scale.

PROTRUSION OF THE EYEBALL.

The next point to be noted in the examination of a patient's eye is the amount of *protrusion* of the eyeball, which is sometimes a symptom of very great importance, and the principal symptom in a number of diseases of the eye or orbit. When there is any inflammation or swelling, or tumor or growth of any kind pressing upon the ball, it protrudes outward, because, being encased in the bony orbit, that is the only direction in which it can recede before the offending material.

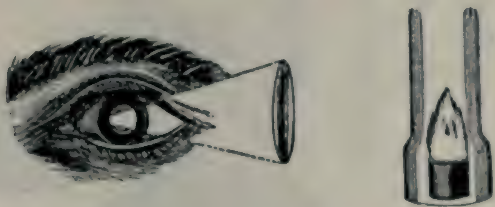
If the protrusion attains such a degree that the lids no longer suffice to entirely cover the surface of the cornea, the condition is a serious one on account of the pernicious effects it entails upon this membrane and other portions of the eye. The cornea becomes dry, rough and scaly, then ulcerates and becomes opaque, until it is finally destroyed and blindness results.

This condition of protrusion is known as exophthalmus, and can only be measured approximately and without any great precision. It usually suffices to gain a relative knowledge of its degree as compared with the normal condition; or, if the exophthalmus is great enough to prevent closure of the lids, then we notice the size of the palpebral opening.

The eyes of myopic patients are large and prominent, with occasionally some protrusion, but scarcely enough so to justify the term exophthalmus.

EXAMINATION OF THE CORNEA.

The condition of the conjunctiva next attracts our attention, and we notice whether it is clear and transparent, or congested and inflamed. Attention should next be given to the condition of the cornea. The chief characteristics of this membrane are its uniform transparency and its smooth reflecting surface, which, as a convex mirror, affords an erect but diminutive image of the objects placed in front of it. In the healthy eye the transparency of the cornea allows us to see the fibrillations and the color of the

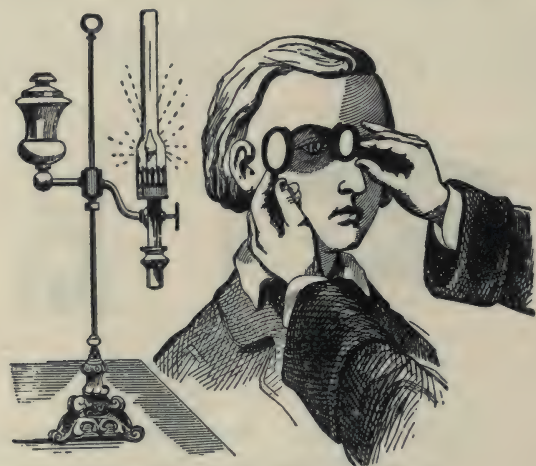


Illumination of cornea
[From "Wells' Diseases of the Eye," by Bull.]

iris with perfect distinctness. These may be concealed, or seen but imperfectly, either on account of some opacity of the cornea, or on account of turpidity or cloudiness of the aqueous humor, due to the presence of blood or inflammatory products in the anterior chamber. When the cornea itself is cloudy, the cloudiness or opacity is at first seldom uniform over the whole surface, and hence the more transparent portions will often allow us to see the condition of the aqueous humor and of the iris beneath. Slight opacities of the cornea are liable to escape a cursory examination by reason of the direction in which the light falls upon them, or because they resemble in color the background of the iris or pupil behind them. In order to get the best possible view of the cornea, the patient should be seated facing a good, large window admitting plenty of diffuse daylight, but not exposed to the direct rays of the sun. The eye under inspection should not only be turned successively in various directions, but the optometrist should also vary his own point of view; and in any case of doubt, he should employ a convex lens to concentrate light upon the parts observed, and, if necessary, a second convex lens to act as a magnifier, with which the better to examine the illuminated surface. Or the same procedures can perhaps be more satisfactorily done by the use of lamplight.

FOCAL OR OBLIQUE ILLUMINATION.

Inspection of the cornea in this matter may show that its surface is more or less cloudy, or irregular in shape, or ulcerated,



Use of illuminating and magnifying lenses.
[From "Wells' Diseases of the Eye," by Bull.]

or marked by the cicatrices of former ulcers, all of which conditions will materially affect the sight, and in such a way as not to be remediable by glasses. Opacities of the cornea will appear by this oblique illumination (which is reflected light) of a grayish or whitish color, while the same spots seen with the ophthalmoscope (which is transmitted light) will appear as dark spots upon a bright red background. It has many times happened that an optometrist has spent considerable time in fruitless efforts to find a lens that will improve his patient's sight, much to his own discomfiture and his patient's disappointment, when finally a chance glance at the cornea shows a cloudiness or opacity that cannot be remedied by any combination of lenses.

We next examine the aqueous humor, which should be perfectly clear and transparent like water. When the cornea and aqueous humor are both transparent, they allow the condition of the iris and of its central aperture, the pupil, to be clearly seen.

EXAMINATION OF IRIS AND PUPIL.

The chief characteristic of the healthy iris is its lustrous striated surface; while the chief characteristics of the healthy pupil are its circular outline, its free mobility, and its clear, bright blackness. After fifty years of age this blackness is usually exchanged for a more or less grayish or yellowish tint, due to the senile changes in the crystalline lens.

Inasmuch as the pupil contracts and dilates with the increase and diminution of tension of the accommodation, it can be seen that the mobility and diameter of the pupil may afford indications as to the state of the accommodation.

By oblique illumination the pupil contracts when light is thrown directly into it; and dilates when light is removed. Irregularity in the shape of the pupil is often a result of iritis, which leaves adhesions of the iris to the crystalline, called posterior synechia. This condition becomes more evident when an attempt is made to dilate the pupil by atropine.

In childhood the pupil is larger and active in its changes of size; with age it becomes smaller and less active. The reaction of the pupil to light is its contraction when exposed to a bright light, and its dilatation when the light is removed. It may be tested by alternately shading and exposing the eyes in daylight before a window; or by concentrating artificial light upon the pupil by means of a mirror or a convex lens suddenly and then turning the pencil of light off the eye. In this way the slightest reaction to light can be detected, and this is really of more interest than the size of the pupil.

The pupil may fail to respond to light on account of adhesions or rigidity of the iris or loss of function in the retina and optic nerve tracts. When there is no reaction to light but to accommodation and convergence, the condition is known as the *Argyll-Robertson pupil*, which is one of the early symptoms of locomotor ataxia.

When light is thrown on one eye the other pupil reacts equally. An inequality in the size of the pupils or a slowness in their reaction, is dependent upon changes in the central nervous system. The pupil dilates from fear and from nervous causes. It contracts with accommodation and convergence, and during sleep.

By oblique illumination the color of the pupil changes from black to gray, such change being more noticeable in aged people, so much so that it is sometimes mistaken for cataract; this error, however, is quickly dispelled by the ophthalmoscope.

QUESTIONING THE PATIENT.

This inspection or examination of the exterior of the eye, which has occupied so much space and taken so long to describe, can, after a little practice, be completed in a few minutes, and we are then ready to proceed with the examination of the refraction and visual acuteness.

The optometrist should ask his customer how and in what way his eyes trouble him. Don't put the question in such a way as to ask what is the matter with his eyes, or he may reply that that is what he wants you to tell him; but the question should be framed in such a shape that he will be led to tell the optometrist the train of symptoms of which he has to complain.

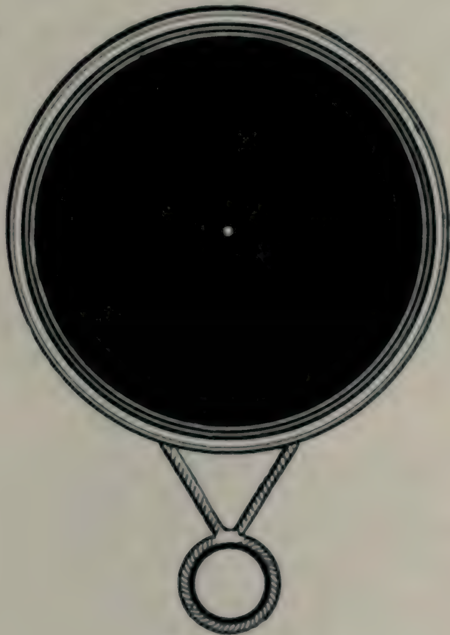
Unless the patient is too prolific, and is disposed to take up too much of your time with his tale, it is well to patiently listen to him, and allow him to make his statement in his own language. He may say that he sees well enough at a distance, and that his principal difficulty is in reading, especially in the evening; or that after reading awhile the print runs together, or the eyes water; or perhaps he is compelled to stop awhile and close his eyes and rub them before taking a fresh start. The optometrist will at once recognize these symptoms as pointing toward hypermetropia as the probable cause of the trouble, or, in a middle-aged person, toward presbyopia.

Or he may say that he has no difficulty in reading or writing, or any close work, but that he cannot recognize his friends across the street, or that he cannot see the expression of the preacher's face in church, which symptoms would at once lead the optometrist to suspect myopia. Or perhaps the complaint may be that vision is not satisfactory for either reading or distance, with pain and discomfort on using the eyes, in which case astigmatism would be suspected.

PIN-HOLE TEST.

In any case of imperfect vision, it is desirable to determine in the commencement of the examination whether the defective sight is due to some error of refraction, or to some organic disease of the eye. Fortunately we possess in the "pin-hole test" a method by which this point can be easily and quickly determined.

A black metal disk having a small pin-hole perforation in its center (such as is found in all the more complete trial-sets of test-



Pin-hole disk.

lenses) is given to the person, and he is told to hold it quite close to the eye under examination, care being taken to see that the pin-hole is directly in front of the center of the pupil. This admits into the eye a small pencil of the rays of light, which passes through the axis of the refractive system of the eye, forming a clearly defined image for all distances. If this noticeably improves vision on the distant test-card, then it is known that the refractive system of the eye is at fault, and that a similar or greater improvement in sight can be expected from glasses; but if, on the contrary, vision is not at all improved by the pin-hole disk, then some organic disease of the eye may be suspected, which is not remediable by glasses, and which removes the case beyond the province and aid of the optometrist. The pin-hole disk can be used in the trial-frame over one eye, while the other is excluded by the opaque disk; but the suggestion was made above to allow the patient to hold it in his hand, and in this way it perhaps could the better be placed directly in front of the pupil.

The pin-hole test is a simple method, as reliable as it is simple, and we always advise optometrists who read these lines to use the pin-hole test in every case of defective vision. If the optometrist thus discovers early in his examination whether or not it is a case of refractive error he has to deal with, he will save much valuable time (which he might otherwise spend in trying to fit a case that could not be helped by glasses), and he will be in a position to give reliable advice if it is a case which does not come within his province to be fitted with glasses. If the optometrist finds it to be a case of organic disease, he fails to do his duty unless he advises the patient to consult a physician; while if the pin-hole test shows it to be a refraction case, the optometrist will continue his examination by following the methods given below.

EMMETROPIA.

As it is proposed in this work to treat of vision and the errors to which it is subject, and as in former chapters the various anatomical parts concerned in the sense of sight have been explained and demonstrated, and also the effect of lenses on rays of light, we are now in a position to consider the eye as an optical instrument, and to examine the normal eye in its power to see and appreciate the objects all around us.

The normal eye will be mentioned first, although we believe that there are very few persons who possess perfectly normal eyes and vision even from their birth, although doubtless there are many such persons who have had no trouble with their eyes, and who have always supposed their sight to be equal to that of the perfect standard.

By the normal or emmetropic eye is meant one that, when in a state of rest, has its refractive power so adjusted that it can see distinctly at a remote point or infinity; so that parallel rays of light are brought to an exact focus on the retina at the yellow spot without any effort on the part of the eye or its accommodation. This is called *emmetropia*, meaning that the eye is in measure.

If an emmetropic eye be tested, what will be the result of the examination as regards the vision at a distance and at the near point? The vision will be 20/20 or one, and the nearest point of distinct vision for the smallest type will be about four inches, if the person examined be not over twenty years of age. The cornea, aqueous and vitreous humors, with the crystalline lens, are the refractive media of the eye. Combined, they represent a biconvex lens of rather less than one-inch focus. The optical center of the combination is a little behind the crystalline lens, and the retina is a sensitive screen placed at the focus of the combination.

COMPARISON WITH A MAGIC LANTERN.

Our perception of the outer world is due to the formation of real inverted images on the retina, although we are unconscious of the inversion. In order that objects may be seen distinctly, their images must be accurately focused on the retina. We have already considered the change that takes place in the eye by which we are enabled to tell the time on the distant tower-clock, and compare the figures there with those on our own watch held in our hand, which power of adjustment for near and far vision is known as the accommodation of the eye.

The principles involved in the construction of an *emmetropic* eye may be appropriately illustrated by a reference to the magic lantern or stereopticon, with the use of which every one becomes more or less familiar in his boyhood days. We soon learned in using this instrument that the screen must be at the proper distance; that the lens must be of the proper refractive power, and must be moved in or out to the proper position, in order to produce a clear and distinct image upon the screen. In other words, the power and position of the lens and the distance of the screen bear certain fixed relations to each other, which relations cannot be altered without marring the clearness of the image produced.

The same relation exists between the refracting media of the eye (corresponding to the lens of the magic lantern) and the retina (corresponding to the screen on which the magic lantern pictures are thrown). A clear image can be formed on the retina only when the refracting media are of the proper refractive power, and the retina situated at their proper focal distance, in which case the parallel rays of light entering the eye are brought to a focus exactly at the position of the retina, that is, on the retina. In the construction of such an eye, all the conditions having been complied with in conformity with the laws of optics, a perfect image is necessarily formed on the retina, and this being conveyed to the brain by the optic nerve produces normal and comfortable vision.

And disturbance between these relations blurs the distinctness of the image formed and produces abnormal vision, and this disturbance may result as follows: either the refracting media of the eye may have too much or too little refractive power, or the retina may be too near or too far from the lens, or sometimes both conditions may be found in the same eye.

Thus the significance of the word *emmetropia* can be appreciated, which means "an eye in measure." On the other hand, when the relation between the distance of the retina and refracting power of the media does not correspond, the condition is very appropriately called *ametropia,* which means "an eye out of measure." The student should clearly understand the significance of these two words, so that when in his reading he encounters either one of them, there will at once flash into his mind a perfect understanding of the conditions involved.

Thus it will be seen that the length of the eyeball, or, in other words, its axial diameter, plays a very important part in, and, in fact, is the fundamental conditions of, two of the common errors of refraction which the optometrist is daily called upon to correct with lenses.

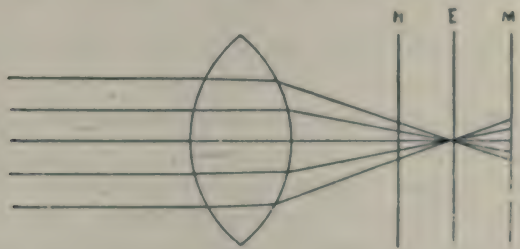
EXPERIMENT WITH CONVEX LENSES.

The conditions present in *emmetropia* and *ametropia,* and the meaning of *in measure* and *out of measure,* can be perfectly demonstrated by an experiment:

A strong convex lens is taken and held in such a way that rays from distant objects will pass through it and be refracted, and form an image on a piece of cardboard held at the principal focus of the lens. The card may be moved nearer to and farther from the lens until the exact position is found where the most perfect image is formed. If a convex lens of ten dioptres is used, this position will be at four inches from the lens, and everything is exactly "in measure," and this corresponds to the condition known as emmetropia.

The card may now be moved nearer to the lens, and then, instead of a perfect image being formed, there will be seen circles of diffusion, because the rays strike the card before they have had an opportunity to converge to a focus, and hence everything is "out of measure." This corresponds to the condition known as hypermetropia. If another convex lens be interposed it will add to the strength of the original lens, and thus bring the rays to an earlier focus; and if the additional lens be of the proper strength, this focus will be just at the point where the screen is placed.

If, on the other hand, the card be moved farther away, a perfect image can no longer be formed, and again we see nothing but diffusion circles or a confused patch formed on the card, be-



Focus of parallel rays of light in emmetropia as compared with hypermetropia and myopia.

cause it is farther away than the principal focus of the lens, and the rays only strike it after they have converged to a focus and then diverged. Here, again, everything is "out of measure," and this corresponds to the condition known as myopia. Here the rays have come to a focus too soon; and if a concave lens be now interposed, it will detract from the strength of the original lens, and thus bring the rays to a later focus; and if this concave lens be of the proper strength, this focus will be just at the point where the card is placed.

These illustrations explain how hypermetropia can be corrected by convex lenses and myopia by concave lenses, and that emmetropia needs no correcting lens. It should be further stated that the above remarks about the emmetropic eye and the ametropic eye all refer to it when it is in a state of rest; that is, when there is no accommodative effort, and when the eye is adjusted for parallel rays or for distance. Or, in other words, that eye only can be considered as emmetropic that exactly focuses the rays of light upon its retina when in a state of rest; and that eye ametropic that is unable to thus focus the rays when passive or at rest.

An emmetropic eye, then, is said, in a state of rest, to be adjusted for infinity, because it is adjusted for parallel rays, and only those rays are absolutely parallel that proceed from infinity. But in reality, and for all practical purposes, any object situated at fifteen or twenty feet or beyond emits rays that are so nearly parallel, and that cannot be demonstrated to be not parallel, that they are called parallel, and as such are used for determining the refraction of an eye, that is, whether it is emmetropic or ametropic. And while the expressions infinity and infinite distance are frequently used, yet in practice we commonly use a distance of twenty feet without disturbing the accuracy of our calculations.

DIFFERENCE BETWEEN REFRACTION OF EYE AND ACUTENESS OF VISION.

The "refraction of the eye" and the "acuteness of vision" are frequently confounded. They are two very different things, however, and the optometrist should have a clear understanding of the difference between them, and how to be able to clearly distinguish one from the other, although in practice it is customary to determine them together. In simple words, the *refraction* is the function of the *dioptric apparatus* of the eye; while, on the other hand, the *acuteness of vision* is the function of the *nervous system* of the eye. The *refraction* of the eye refers to the action of that organ on the rays of light that enter it, while *acuteness of vision* has reference to the image formed on the retina, and to the sharpness of sight as perceived by the brain.

Refraction may be perfectly normal, and still the eye not be able to see, if the nervous apparatus fails to perform its function properly; that is, the dioptric apparatus may be such as to exactly focus the rays on the retina and form an image there; but no matter how perfect the image may be that is formed there, if it is not conveyed to the brain by the optic nerve there can be no resulting vision. While, again, the acuteness of vision may be normal, in spite of great anomalies in the refraction, if these latter are properly corrected by glasses. While there may be refraction without acuteness of vision, there can be no acuteness of vision without refraction. Refraction is the first step, or cause—acuteness of vision is the second, or the result.

The refraction of all eyes, even of the eyes of a dead person or the enucleated eye of any animal, can be determined: but, on the other hand, the acuteness of vision can be determined only for a living eye, for the determination of which, however, it is necessary that its possessor be able to express himself clearly in regard to the luminous impressions received on his retina and conveyed to his brain. Refraction may be an objective symptom, while acuteness of vision is a subjective symptom.

Acuteness of vision is for the retina what tactile sensibility is for the skin, and the condition of the two functions is determined in an analogous manner. We seek in both for the smallest distance between two points which can be perceived separately. For the skin, the mechanical pressure of the two points of a pair of compasses is made use of; for the retina, the impressions produced by the retinal images of two luminous points. The determination of the acuteness of vision consists, therefore, in the determination of the smallest retinal image, the form of which can be distinguished.

We desire here to call the attention of the optical student to a distinction and a difference—it is not simply the smallest retinal image that can be *perceived* that gives the measure of the acuteness of vision, but it is the smallest retinal image whose form can be *distinguished*. The perceptibility of the smallest retinal image depends solely on the luminous intensity of the point that produces the image. One luminous point does not measure the visual acuteness or the distinction of forms, but simply the perception of light, or the faculty which the retina possesses of distinguishing differences of brightness.

THE EFFECT OF ILLUMINATION ON THE ACUTENESS OF VISION.

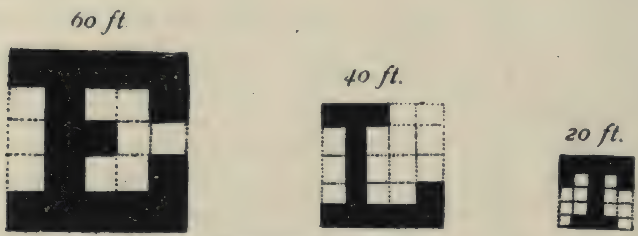
The acuteness of vision, or the faculty of the retina to perceive forms, depends on several conditions:

1. Primarily on the sensibility of the retina.
2. On the adaptation of the retina.
3. On the general illumination.
4. On the sharpness of the retinal image.
5. On the intensity of illumination.

The adaptation of the eye to the illumination under which it acts is a condition which it becomes necessary to take into account in all experiments relative to the distinction of the degrees of clearness and of colors.

In passing from an illumination of a less to one of a greater intensity, or inversely, it takes a certain length of time for the retina to become accustomed to the altered illumination and to put itself in harmony with it. We know that the acuteness of vision varies with the general illumination as that of a clear, sunny day compared with that of a dark, cloudy day. This is patent to every oculist and optometrist who uses diffused daylight in the examination of his cases, and causes variation and confusion in the records of those cases which are examined on several different days, when these varying conditions of brightness and gloominess prevail.

The sharpness of the retinal image depends essentially on the



Test-types of Snellen.

transparency of the dioptric media, the regularity of their surfaces, and the adjustment of the eye to the distance of the object. The results of numerous experiments have proven that it is essential that the two points of a retinal image, in order to be clearly distinguished one from the other, must be separated by a certain small distance. Such a retinal image, that is, the space or distance by which these two points are separated, corresponds in the normal emmetropic eye to a visual angle of one minute.

The test-types of Snellen are those in most common use for the determination of the acuteness of vision, and he has based his types on the point mentioned above (that a visual angle of one minute is the smallest that can be perceived), and he has made a selection of such letters that the width of each line of a letter, at its proper distance from the eye, will form two opposite points on the retina, which, with the nodal point, subtends an angle of one minute; that is, each of the black lines of every letter will form an image of that size in its smallest part. Now if we take five lines or five spaces for the size of each letter, we will then have formed an image on the retina which will subtend an angle of exactly five minutes. For the majority of cases this is the smallest image and forms the smallest visual angle that the normal retina can comfortably appreciate. Each series or size of Snellen's letters is marked by a number which indicates in feet the distance at which the letters appear under an angle of five minutes, and the lines of the letters at an angle of one minute.

DEGREES, MINUTES, SECONDS.

It may, perhaps, at this point be well to stop long enough to explain the meaning of the terms degrees, minutes and seconds. A degree is expressed by this sign (°), a minute by this sign (′), and a second by this (″). These are matters on which a great many students have very confused ideas. Every circle, no matter how large or how small it may be, is divided into 360°, each degree is divided into 60′, and each minute into 60″, a second being the smallest sub-division. If the circle is large these sub-divisions can be very easily seen, but if the circle is small the sub-divisions become microscopical. In a circle of one foot in diameter, we can easily see the divisions into degrees, and can possibly detect the sub-divisions into minutes, but it will require a magnifying glass or a microscope to detect the dimensions of an angle of one second. On the other hand, it has been stated that if a circle is taken with a radius of the moon's distance from the earth, it can be subdivided into seconds which will each represent a distance or space of one mile. A little reflection will show that a degree or a minute, or a second does not represent any fixed or exact space or size in inches or feet, but must be considered in connection with the diameter or radius of the circle, be it large or small, and as only indicating a fixed and definite proportional part of that circle. This is an important point to remember, as otherwise great uncertainty and confusion might arise in the mind of the student when these divisions of a circle are mentioned.

MINIMUM SIZE OF TEST-LETTERS.

As an illustration of the comparative size of degrees, minutes and seconds, we might take the letter that should be visible at a distance of one hundred feet. The diameter of this circle would be two hundred feet and the radius one hundred feet, and the circumference a little more than six hundred feet. This six hundred feet is the length of an imaginary circle one hundred feet away, with the axis of vision as the center of the circle. If we divide this by three hundred and sixty we will find the height of one degree; and if we divide this by sixty we will find the height of one minute, which is just the width of one of the lines or spaces of the letter. 600 divided by 360 = 1 2/3 feet as the size of one degree. 1 2/3 divided by 60 = 1/36 foot as the size of one minute.

The same illustration may be applied to the reading type, which we will suppose is located at fifteen inches, which is the proper distance to hold a book for continuous reading. This gives us the radius of the circle, the diameter of which would be thirty inches, and its circumference (being a little more than three times its diameter) about ninety inches. This circumference of ninety inches is divided into three hundred and sixty degrees (as every circle is), which gives us one-fourth inch as the size of one degree. This quarter inch is divided into sixty minutes, which gives us 1/240 inch as the size of one minute. That is, in a circle of thirty inches diameter and ninety inches circumference, an angle of one minute is 1/240 inch wide at its base. This, then, is the width or size of the smallest object that can be discerned at a distance of fifteen inches while five times this size, 5/240 inch or 1/48 inch, is the size of the smallest letter that can be pleasantly and comfortably seen at this distance. Therefore, the letters are so constructed that the width of each line or limb of a letter shall subtend an angle of one minute, while the letter itself shall subtend an angle of five minutes.

This is the principle that governs the size of the letters, and it was determined by no other way than by repeated experiments. Long-continued observations seemed to prove that the normal eye was not capable of discerning any object that did not subtend an angle of one minute, while for comfortable and continuous vision it was necessary that the object be five times as large. This is the principle that Snellen put to practical use in the construction of his test-letters.

THE VISUAL ANGLE.

The illustration below shows that the visual angle is always the same for the various letters at their respective distances. The angle produced by the large letters at one hundred feet is the same as that produced by the small letters at twenty feet, in each case being an angle of five minutes. This is the case with all the intermediate letters, as at fifteen feet, thirty feet, seventy feet, and at two hundred feet, the angle remaining the same in every case. Therefore, we find that an eye that can see the twenty feet letters at twenty feet can, with equal ease, see the seventy feet letters at seventy feet, and the largest letters at two hundred feet.

The size of the visual angle depends upon two factors—the distance of the object and its size. The farther an object is removed from the eye, the larger it must be in order that the visual

Visual Angle.

angle may remain the same. As this visual angle remains unchanged and the different letters form an image of the same size, we might think the letters were all of the same magnitude, if our experience and judgment did not correct such an impression and convince us that the letters are of various sizes and placed at different distances.

ACUTENESS OF VISION.

The smallest distance at which two points can be separately distinguished is the measure of the visual acuteness. The eyes perceive two stars when they are far enough separated, while if they are brought closer together the two stars blend into one. If the stars are separated by an angle of one minute more, they are perceived as two distinct stars; while if they are separated by an angular distance of less than one minute they run together, as do the stars composing the "milky way."

The *acuteness of vision* (the abbreviation of which is usually written V.) is expressed by a fraction, the numerator of which denotes the distance at which the card is placed, and the denominator the number of the line which can be read. For instance, if the card is hanging at a distance of twenty feet from the patient, who is able to read the No. 20 line, we make a record as follows: V. = 20/20. When tested in this manner V. = 20/20 is universally accepted as the normal standard, and yet it must be regarded only as the general average. Young persons under forty years, with emmetropic eyes, can usually see somewhat better than this, while with the advance of age the acuteness of vision gradually diminishes. The following table shows the average acuteness of vision at the different ages:

10 years	$\frac{22.5}{20}$
20 "	$\frac{22.5}{20}$
30 "	$\frac{22}{20}$
40 "	$\frac{20.5}{20}$
50 "	$\frac{18}{20}$
60 "	$\frac{14.5}{20}$
70 "	$\frac{13}{20}$
80 "	$\frac{11}{20}$

Therefore, it is not at all uncommon to meet with cases that see better than 20/20. Their vision then is above the normal standard, and its acuteness is equal to 20/15 or sometimes even 20/10, by which is meant that they can read letters at twenty feet which ordinarily can be seen only at fifteen feet or at ten feet: therefore, their vision is above or better than the standard. This should cause no surprise, as it not infrequently happens. Many healthy young persons, whose dioptric media and nervous elements are perfect, enjoy an acuteness of vision greater than that which Snellen has taken as the standard. The acuteness of vision of Snellen, however, is not the *maximum*, but is to be taken as the *average* of the different ages.

The maximum acuteness of vision could not serve us in practice, where we desire to know what is to be considered as normal, and the limits beyond which it must be considered as abnormal. But some standard must be adopted, and Snellen's test-letters at twenty feet is about the greatest distance for normal vision in the largest number of cases. And taking this as the standard, we should desire in all our examinations to make, if possible, the person examined at least see 20/20. This is the standard toward which we work and endeavor to reach by the proper correcting glasses, when we have a patient whose visual acuteness is below the normal.

A SMALLER VISUAL ANGLE.

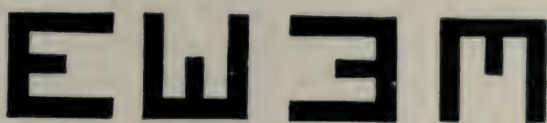
Some letters are easily seen and distinguished by their shape, as for instance **O** and **L**, without the need of seeing distinctly the five separate parts of height and breadth. And besides as mentioned above many young people can read lower than the No. 20 line; for these reasons, for many persons, the letters of the Snellen scale are a little too large.

This has led to the preparation of a card of smaller letters, subtending an angle of four and a half minutes, and some are even made on a four-minute angle. But with any test-card the various letters of even the same size are not all seen with the same distinctness. For instance, **B** and **S** are letters difficult to distinguish and usually requires the full five-minute angle.

Some of the test-types are numbered in the metric system, in which 30 meters would equal about 100 feet, 12 meters about 40 feet, and 6 meters 20 feet. In this case if the test is made at the usual distance of six meters, the fraction representing the acuteness of vision would read 6/6 if vision is normal, or 6/9, 6/12, 6/30 as the case may be when vision is impaired.

ILLITERATE CARDS.

Among hospital patients, some are so illiterate that they cannot read letters. In such cases we have to use a sign, adopted also by Snellen, in the shape of the letter **E,** which is square, with one side open and the ends pointing in different directions, as upward, downward, to the right and to the left.



Test-types for those who cannot read.

This method is of service also with children and mutes. The card is of the same size and appearance as the ordinary test-card, the above characters in the various sizes taking the place of the regular test-letters. The patient is asked in which direction the limbs or open part of the character points; this is the only distinction he can make between them. The result is recorded in the same way as a regular examination with test-types, as V. = 20/20, or 20/30, and so on. But it has been found that where persons are so illiterate or children so young as to be unable to read the regular letters, their answers will be more or less unsatisfactory even with the characters above described, and it is consequently often a very difficult matter in such cases to ascertain the acuteness of vision, to determine the refraction, and to decide just exactly what is the proper glass to give them.

Snellen's series of letters, although the ones most widely known and in most universal use, are not the only ones which have been constructed for the determination of the acuteness of vision at a distance; but none of the others have any advantages over Snellen's, which are admirably suited for their purpose. And the name of Snellen has consequently become a "household word" with optometrists all over the world.

This, then, is our practical method or test for ascertaining the acuteness of vision, and it will be noticed that it is not only very simple and practical, but it is also eminently rational and affords us a reliable test for all errors of refraction. It also excludes for the greater part the exercise of the accommodation, and places the retinal images of the emmetropic and ametropic eyes on the same equality as to size.

THE EFFECT OF LENSES ON THE SIZE OF THE RETINAL IMAGE.

This last advantage is a very great one, and in order that it may be more fully appreciated it will be necessary to consider the influence of correcting lenses on the acuteness of vision. It is a fact of common observation with which the beginner in optical studies is familiar, that convex lenses magnify, whilst concave lenses diminish the size of objects. From this fact it might be supposed that hypermetropes, by the aid of their correcting glasses (which are always convex), would receive retinal images of larger size than emmetropes and myopes; and that myopes, on the other hand, by the aid of their correcting lenses (which are always concave), would receive retinal images of smaller size than emmetropes and hypermetropes. It would, therefore, seem at first sight as if correcting lenses would completely mar the results of our determination of the acuteness of vision in so far as they might change the fundamental condition, viz.: the equality in the size of the retinal images coming from the same objects.

But then, again, it must be remembered, and it can be easily understood, that a hypermetropic eye, which is a flat eye, other things being equal, will receive (on account of the lack of converging or magnifying power of the eye) retinal images which are smaller than those received in a longer eye, that is, in an emmetropic or a myopic eye. The smallness of the hypermetropic eye and its lack of refractive power have, therefore, an effect on the visual acuteness and on the retinal image just the opposite of its correcting lens. When we examine the condition of the myopic eye we find the same principle holds good in producing an opposite effect; here the largeness of the eye and the increase in its refractive power have the effect (within the proper limits) of increasing the visual acuteness and enlarging the retinal image, which stands in contrast to the effect of its correcting concave lens. Now the interesting question occurs, which of these two influences is the greater? Whether, in the case of the hypermetropic eye, the diminishing effect of the refractive condition of the eye is more or less counterbalanced by the magnifying effect of its correcting convex lens; and whether, in the case of the myopic eye, the magnifying effect of the refractive condition of the eye is more or less counterbalanced by the diminishing effect of its correcting concave lens? This is a question of considerable practical importance, whether we should expect to find in a hypermetropic eye wearing a convex lens a visual acuteness greater than that of an emmetropic eye, simply because one wears magnifying glasses, while the other sees only with the naked eye; or whether, on the other hand, we ought to expect to find on the part of the uncorrected hypermetrope a diminished acuteness of vision corresponding to his normal retinal perception, because the hypermetropic eye, on account of its shortness, receives smaller retinal images.

Again, the question occurs as to whether a myopic eye, which, with its correcting lens, reads exactly the same letters as the emmetropic eye at the same distance, has a natural greater visual acuteness than the emmetropic eye, simply because it is able to distinguish these letters in spite of the diminishing effect of the concave lens. These questions can be solved only by means of minute and tedious calculations mathematically worked out; but as the aim of this work is essentially practical, it seems best to omit as much as possible all dry and uninteresting details, and we will therefore only glance at the results of the researches made in this direction.

DISTANCE OF LENSES FROM EYE AFFECTS THE RESULTS.

The various forms of ametropia may be corrected by lenses of differing strengths, according as they may be placed at a greater or less distance from the eye. It has been determined, and it is generally accepted as a fact, that if the correcting lens of an ametropic eye be placed in the anterior focus of the eye at the proper distance in front of the cornea, the retinal image of this ametropic eye should be of the same size as that formed in an emmetropic eye.

On the other hand, if we correct a case of hypermetropia by a convex lens (stronger, perhaps, than is really necessary) placed nearer to the cornea, the retinal image will be smaller, because the lens is not placed in a position sufficiently favorable for completely overcoming the diminishing effect of the refractive condition of the eye; while a weaker lens may be used if it is placed farther from the cornea than the point indicated, and the retinal image will be larger because the lens is placed in such a position as to be able to more than neutralize the natural refraction of the eye.

An analogous effect is produced in the case of myopia. Here the diminishing effect of the lens makes itself felt in proportion as it is removed from the anterior focus of the eye, while the magnifying effect of the greater length of the eyeball preponderates and is manifest when the correcting lens is approached nearer than the indicated point. These facts suffice to show the undoubted advantages of determining the visual acuteness at a distance.

DISTANCE OF TEST-CARD.

Now the question occurs as to what is the most favorable distance for determining the acuteness of vision. We determine the refraction and the visual acuteness at the same time, and this should be done at such a distance as to exclude the accommodation as much as possible. For this purpose, by common consent, a distance of twenty feet should be preferred, because rays proceeding from that distance are so little divergent and are so nearly parallel as to be considered practically parallel, which simulates the rays proceeding from infinity—such parallel rays being exactly focused upon the retina of the emmetropic eye, without any effort on the part of the eye or of its accommodation; and, consequently, at this distance the letters which should be seen at twenty feet will form perfect images upon the retina.

Now while twenty feet is the standard distance, and while it is desirable that every optometrist should, if possible, always test his cases at that distance, yet some optometrists may be so fixed as to make such a distance impracticable, in which cases a shorter distance will have to be used without very materially marring the results of the examination, if it is remembered that the rays from this shorter distance are not perfectly parallel, and that therefore an allowance will have to be made for the exercise of a very slight effort of accommodation in overcoming these scarcely diverging rays.

ILLUMINATION.

In the use of the test-letters, it should be remembered that the illumination of the letters is an important matter, and its variation may make a great difference. It should always be the same, with a good, clear light from a window falling on the card, and the patient so placed that the light will not be unpleasant to the eye—that is, with his back to the window, so that his eyes will be in the shade.

If the natural light was of the same intensity every day, it would suffice if the card could be so placed as to receive its illumination from an unobstructed sky during fair days; but on account of the numerous cloudy and stormy days, when the brightness is variable and deficient, it is better in order to secure an illumination that is constant, to employ artificial light, from a Welsbach gas mantle or electric, placed within ten inches of the card, and partly surrounded by a screen which also acts as a reflector.

TESTING VISUAL ACUTENESS.

The examination is then commenced with the patient comfortably seated facing the card and at the proper distance; and with both eyes open he is asked to name the letters on the lowest line it is possible for him to read, and we then make a record of his answer in our book. If he can read every letter in the No. 20 line we note his vision as being equal to 20/20, or 1, which we write V. = 20/20, the V. being the abbreviation for vision. If he reads this line with great difficulty, or is able to read only a portion of the letters on the line, we note the result as V. = 20/20 scarcely, or V. = 20/20?, the interrogation point signifying the difficulty of reading this line or the doubt with which it is seen. If, however, the patient is able to read only the No. 30 line or the No. 40 line, we write it V. = 20/30 or 2/3, or V. = 20/40 or ½, in one case the vision being two-thirds of the normal and in the other case one-half of normal vision.

In recording the results of the examination of the visual acuteness, it is best not to reduce the fractions that express that acuteness, but to allow them to stand as first written. If we write V. = ½, we know just what proportion of normal vision the eye possesses, but that is all the fraction expresses. But if we write V. = 20/40, we then have a fraction that not only expresses the acuteness of vision, but its numerator and denominator also have a definite meaning, the one expressing the distance at which the patient is seated and the other the size or number of the letters he is able to read.

Having thus determined the visual acuteness of the two eyes together, we then test each eye separately, and again make a record of the result. We then write it R. V. = 20/20, L. V. = 20/20, the R. and L. standing for right and left eye respectively.

After having thus found that in the emmetropic eye V. = 20/20, which has reference to the visual acuteness in the line of direct vision, or at the yellow spot, in some cases it is then desirable to examine the sensibility of the retina in the peripheral portions.

EXAMINATION OF PERIPHERAL FIELD.

Although in the peripheral parts of the retina, V. cannot equal 20/20, as we have already seen, on account of the diminished sensibility of the retina, still it is well to know whether its perceptive elements are in a normal condition, and whether the sensibility of the retina is deficient in any of its parts. The power to see with the peripheral portions of the retina may be much diminished by certain diseased conditions of the eye.

For this examination the most simple manner of test is for the optometrist to sit in front of the patient to be examined; the patient's one eye is covered and he is directed to look at the optometrist's eye with his uncovered eye, the two persons being separated by a distance of about two feet. While the patient keeps the optic axis of his eye directly forward, the optometrist holds his hand, or a pencil, or any bright object, in different positions around and in front of the eye, and as far away as possible.

The farthest point at which the finger or pencil can be seen will show the *quantitative*, and the distance at which the fingers can be counted will show the *qualitative* field of vision.

If the examiner uses his right eye for testing his patient's left eye, and the finger or pencil is held just between the eyes, the operator can compare the field of vision of his own eye with that of the eye under examination.

Another excellent method of testing the field of vision is to place the person to be examined in front of a blackboard, at a close distance (say about twelve inches), and, after covering one eye, direct the patient to look steadily with the other eye at a small mark on the blackboard directly opposite the eye. A piece

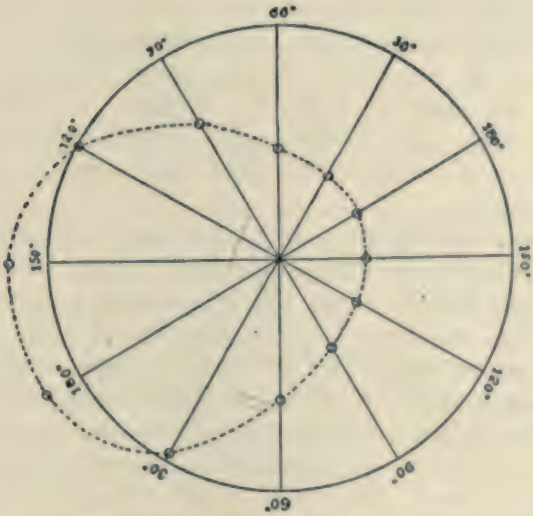


Diagram of field of vision of right eye.

of white chalk, held in the hand of the examiner, is then to be carried along the surface of the board from its outer edge toward the center, on a vertical or a horizontal line, until it can be perceived by the eye under examination simply as a white object, and a mark is then made at that point. In the same way an optometrist will proceed to test all the other meridians of the blackboard, with the same mark as the center, and place a dot at each point where the chalk is first perceived in each meridian.

This record can then be easily transferred to a small sheet of paper by drawing the center dot and the various marks in their proper positions on the respective meridians. Then measure the distance in inches from the center mark outward on each meridian, and then a line drawn to connect each mark will give the size and shape of the visual field.

THE PERIMETER.

An excellent instrument called the *perimeter* has been devised for accurately testing the field of vision. It consists, essentially, of some arrangement to keep the eye and the visual axis in one position throughout the examination, and of an arc capable of carrying a test object to all parts of the field of vision, and of indicating exactly the position of such a test object at any given time. To these necessary parts some perimeters add a registering apparatus; with others the results must be marked on the chart by the observer from the readings he notes on the graduated scales. For recording the results of tests made by the perimeter, it is best to use blank charts, which are printed for that purpose.

The usual perimeter consists of a brass stand with an upright and an arm one-fourth of a circle. At the end of this arm there is a half circle of brass, which is moved on the smaller arc by a pivot in the center. In this there is an opening through which the person examined must constantly look, while the head is steadied by a chin-rest, adjustable to any desired height. This semi-circular arc has a radius of five inches, and is graduated in degrees so that it can be placed to correspond with any of the meridians of the eye. The upright which extends from the stand for the chin to rest upon brings the eye exactly on a level with, and in front of, the opening in the arc. There is, also, a slide moving freely on the arc from end to end, on which is placed a small disk of white paper. Then, with the patient in the proper position, the test is made by moving the slide on the arc toward the center until the disk can be seen. This test gives the quantitative field, while a small letter placed on the disk and used in the same way gives the qualitative field.

This instrument is small, compact and very useful, as by changing the white disk of paper to one of any other color we can test the field for its power to distinguish colors in all the peripheral parts of the retina. It is a fact that the normal field varies in size for the different colors, that for white being the largest. blue next, then red. and that for green the smallest.

SCOTOMATA OR BLIND SPOTS.

After the extreme limits of the field of vision have been mapped out in this way with the perimeter, the slide, with the disk, should be slowly carried completely up to the center. If the white disk should disappear or become blurred at any point, there should be a careful record made of all such points at which the blurring commences, and also the points where it becomes clear again, as it is carried toward and to the center. When all the meridians have been carefully examined and the test completed, it may be found that a certain portion of the retina has lost its sensibility to rays of light, though its functions may be perfect all around this deficient portion. In this manner a diagram is mapped out which reveals any spots of deficient vision on the retina, which are technically known as scotomata, or blind spots, from any cause, such as retinal hemorrhage, etc.

It might be well here to add a word of caution not to mistake the normal blind spot, or "Blind Spot of Mariotte," for one of any danger. This is a small blind island or scotoma that is due to the optic disk or papilla at entrance of optic nerve; the explanation of the deficiency of vision at this point having been already explained in a former part of this work. By repeating the examination of the field of vision at different times, it can be ascertained whether the field is contracting or expanding, and of the presence or absence of any scotomata, as well as of their extent.

SHAPE OF VISUAL FIELD.

The normal field of vision is not circular, as a reference to the above diagram will prove, but extends outwardly about 95°, upward about 53°, inward about 47° and downward about 65°. The shortening of the field upward and inward is due, chiefly, to the projection of the ridge of bone surrounding the upper part of the orbit, and to the bridge of the nose, and also, to some extent, to the fact that the outer and lower parts of the retina have a less acuteness of perception than the upper and inner parts. The acuteness of vision diminishes progressively toward the periphery of the field, and the farther from the fixation point the larger must be the objects in order to be distinguishable from each other.

The above diagram serves to illustrate the projection or extent of the field of vision on the semi-circle of the perimeter to its extreme temporal (95°) and its extreme nasal (47°) boundaries, and also the portion of the retina (*a* to *b*) which corresponds to this extent of field. This diagram also shows that the most sensitive portion of the retina, or, in other words, that portion of the retina which is most used, extends further forward on the nasal than on the temporal side. This diagram further illustrates the remarkable fact that the field of vision extends on the temporal side beyond 90°.

In the use of the perimeter the arc of the circle can be placed at any meridian we desire to test, as it is readily movable on the

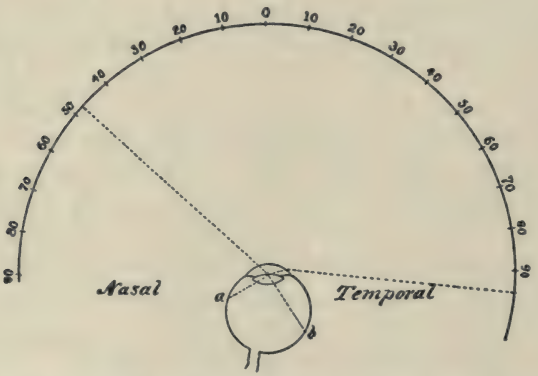


Diagram showing outward and inward extent of field of vision.

center, while at the apex there is a dial with a pointer which marks the meridian at which the arc stands. Generally the examination is made in four meridians, as the vertical and horizontal and the two intermediate meridians, as at 45° and 135°; but the number of meridians examined may be increased to any number the optometrist may think necessary to make the examination complete.

It should be remembered that if there be any contraction of the field of vision shown by the chart it is the opposite side of the retina that is affected; the outer part of the field, as indicated on the chart, representing the inner part of the retina. This is well illustrated in the diagram showing the outward and inward extent of the field.

The above procedures are our methods of ascertaining the extent of the field of vision, by which is understood the space throughout which the eye is able to see or distinguish objects while its visual axis is directed to a certain fixed point in front. And as we call that *direct vision* which pertains to the yellow spot, we call that *indirect vision* which belongs to the retina outside of the yellow spot.

This indirect vision, although it may be very indistinct and imperfect in comparison with central vision, is, however, scarcely less important. Deprived of this indirect vision, a man would be in the position of a person looking through a long, narrow tube, which would allow of his seeing nothing but the object to which the axis of vision is directed. It would be impossible for him to see objects to one side or the other without an incessant turning of his head. We can scarcely imagine the great inconvenience a person would experience in looking about him with such a state of vision, that is, with a visual field restricted to central vision.

INDIRECT VISION.

With such vision it would be absolutely dangerous to attempt to cross Chestnut Street or Market Street in Philadelphia on a busy day, and it would be positive suicide to venture across Broadway, New York, unassisted. As a person walks across a street and looks straight ahead to the opposite side of the street where he is going, he is able, without in the least turning his head or eyes one way or the other, to see perfectly well whether there are any carriages or cars or other vehicles approaching from either direction, or whether the street is clear of danger to pedestrians. So a man can walk along with the most perfect security over the most uneven ground and avoid obstacles that present themselves in his way, without once turning his eyes directly to the ground. So again, a player on the piano fixes his eyes directly on the music before him which he is playing, while at the same time, without changing the direction of his sight, he is able to watch the movements of his fingers over the keys. All this is accomplished by means of indirect vision, the importance of which can hardly be overestimated, and it would not be possible without a healthy condition of the various portions of the retina. If a person would attempt to cross the street with a shade extending forward from each temple, or would try to walk over uneven ground or play the piano with a screen placed horizontally below the eyes, he would meet with such difficulties as to be speedily convinced of the very important service indirect vision renders mankind in the ordinary occupations of everyday life.

The movements which the leader of an orchestra makes with his baton might at first sight to the casual observer seem to be superfluous. But from the above illustrations it can be easily understood that the members of the orchestra, although they cannot turn their eyes from their notes, are able to perceive by means of their indirect vision every movement of their leader. It would be easy to multiply examples of the value of indirect vision, since all our occupations and all our movements in the streets and in our homes would be difficult in the extreme if we did not possess this important faculty of vision. It is this, in a word, which enables mankind to avoid those things which approach or menace him from all sides.

PERCEPTION OF LIGHT AND COLORS AND LETTERS.

The perception of light remains almost exactly the same throughout the whole extent of the retina, but there is a wide difference when it comes to the perception of colors and the visual acuteness. The perception of colors is much less acute in the eccentric portions of the retina than at or near the yellow spot, and diminishes progressively in proportion as it departs from this central point, while the visual acuteness diminishes still more rapidly as the periphery is approached.

In order to illustrate the relation these functions bear to each other, we will take, for example, the standard of measurement for all three functions at the central point of vision to be 1. The perception of light at a point 30° from the center would still be 1, while the perception of colors would be 1/14, and the visual acuteness only 1/4. These figures, of course, have only relative value, but they serve to establish the fact that of the three functions the perception of colors and the visual acuteness diminish rapidly toward the periphery of the retina, the latter more than the former.

These facts are of importance in explanation of these different functions of the retina. It proves conclusively that these three functions are entirely distinct from each other, and cannot be reduced to a single one, as might be thought possible.

PERIMETRY IN DISEASE.

After the optometrist has learned how to examine the limits and functions of the different portions of the retina as shown in this indirect vision, according to the methods just described, it remains to make a practical application of this knowledge to the numerous diseased conditions of the retina in which indirect vision is likely to be found affected, as there is scarcely a lesion of the interior of the eye that is not accompanied by symptoms that can be detected by the perimeter; besides which all the diseases of the brain and spinal cord which are made manifest by eye symptoms, commence by some abnormality in the form and functions of the visual field. But this leads into the consideration of matters of organic disease, which are outside the province of the optometrist and therefore beyond the scope of this book. However, it may be well to take up enough space to briefly mention some of the diseases in which the application of perimetry is of advantage.

In *glaucoma* one of the first symptoms of the disease is a restriction of the visual field. In retinal hemorrhages complete abolition of vision is found in the parts affected, which is manifested by a fixed scotoma in the visual field. In a like manner is the field affected by inflammatory affections of the choroid; and in fact there is no affection of the retina whose progress cannot be traced by the disturbances caused in the field of vision.

DIRECT VISION.

After this digression in considering indirect vision, we now return to the examination of direct vision, which has been shown in the emmetropic eye to be equal to 20/20, but which, as has already been stated, is only the average sight of all ages, and not by any means the maximum degree of sight.

Each eye must be tested separately, by placing the black metal disk in the trial-frame over the eye which is not being tested, and then changing it when the other eye is to be examined. After the optometrist has found that his patient's vision is 20/20, it will enable him to decide several points as to the existence or non-existence of refractive errors. In the first place, he can exclude myopia, for this defect always impairs the visual acuteness, and it is not possible for even the slightest degree of myopia to exist with an acuteness of vision of 20/20. In the second place, he reasonably exclude astigmatism, for this defect also mars the acuteness of vision to a greater or less extent, although it is possible with a vision of 20/20 for a slight degree of astigmatism to be present, especially if it be hypermetropic astigmatism, which the accommodation is able to overcome and conceal. In the third place, when the optometrist finds a vision of 20/20, he must not hastily jump at the conclusion that his patient is emmetropic, for a large degree of hypermetropia may be (and often is, present, but is so concealed by the tension of the accommodation as to not in the least interfere with perfect vision at twenty feet, and the sight will apparently be as good as that of any emmetrope. Hence, the next step is to determine whether or not hypermetropia is present, and if so, what is the amount of the manifest hypermetropia.

TESTING FOR HYPERMETROPIA.

For this purpose the optometrist places before his patient's eye a weak convex lens, say about + .50 D., while the patient looks at the lowest line he is able to read on the distance test-card hanging twenty feet away, which in this case is No. 20. If the letters are dimmed and the sight made worse, then a weaker lens (+ .25) is tried; if the result of this is again to blur the letters, the optometrist may reasonably conclude that the patient has no hypermetropia, at least no manifest hypermetropia, and the case is set down as one in which the refraction of the eye is emmetropic.

FOGGING METHOD IN HYPERMETROPIA.

Instead of commencing with weak convex lenses and trying to increase, or if weak convex lenses are rejected, the optometrist may commence with strong convex lenses and reduce. This is the so-called "fogging method," because distant vision is fogged by means of strong convex lenses. A plus sphere may be used sufficiently strong to more than overcome any effort of accommodation that may be exerted. This practically makes the eye artificially myopic, and then this over-correction is slowly reduced by concave lenses placed in front of the convex.

Suppose we had a case in which the vision equalled 20/20 and the patient rejected even + .25 D. A + 3 D. lens may be placed in the trial-frame, which would at once fog the vision, make the eye myopic, and blot out all the letters on the card except perhaps the largest one at the top, the No. 200. By waiting a few seconds the ciliary muscle may show some disposition to relax and the large letter become a little clearer.

We then proceed to correct the artificial myopia by the use of concave lenses in front of the convex, commencing with — .50 D. and increasing .25 D. at a time until the vision is restored to 20/20. Then the addition of the two lenses, or perhaps some may say the difference between them will represent the amount of hypermetropia that has been uncovered. For instance, if the No. 20 line becomes perfectly clear when we reach — 2 D., then the hypermetropia is equal to + 1 D., which is the result of the algebraic addition of + 3 D. and — 2 D., or, as you may express it, the difference between them.

MANIFEST HYPERMETROPIA.

If, on the other hand, with the convex lenses of .25 D. or .50 D. the sight remains just as good as it was before, or if it is made better, then the case on hand is proven to be one of hypermetropia, and the optometrist proceeds to determine the degree of the defect by trying a + .75 and a + 1, and keeps on trying still stronger lenses.

In ascertaining the degree of hypermetropia in any case under examination, the optometrist places before the eye stronger and stronger convex lenses until he reaches a lens that begins to blur the letters slightly and with which the patient is not able to read the No. 20 line so clearly. The optometrist should then make a note in his record book of the strongest convex lens that improves sight, or the strongest convex lens through which sight is as good as without any lens, which lens will represent the amount of the manifest hypermetropia. It should be written H. m. (which is the abbreviation for manifest hypermetropia) = + 1 D., as the case may be. This is the examination of a case, then, in which, although the acuteness of vision is normal, the refraction of the eye is abnormal, being hypermetropic.

If, however, the test of the patient's vision falls below the normal standard, that is, if at twenty feet he is able to read only the No. 30 line, or No. 40, or No. 70, his vision being 20/30, 20/40 or 20/70, the question then arises: "What is the optical defect present that causes the impairment of vision: is it hypermetropia, or myopia, or astigmatism, or amblyopia?"

By following the method just outlined above, the examiner is able at once to determine whether or not it is a case of hypermetropia.

TESTING FOR MYOPIA.

Having, then, excluded hypermetropia as one of the possible causes of the impaired vision, the optometrist should next proceed to determine whether myopia is present or not; and this is done by testing the eyes with concave lenses. He should commence with a weak concave lens, — .50 D., or even in some cases a — .25 D., and if this lens causes a marked improvement in sight, it proves to the optometrist's mind the presence of myopia. He then tries successively stronger and stronger concave lenses, at intervals between them of .50 D., until he reaches a lens that raises vision to 20/20. The weakest concave lens that enables the patient to read the No. 20 line at twenty feet will be the measure of the myopia. In cases of high myopia it is impossible, in the majority of the cases, to find any lens that will bring the vision up to 20/20, and in such a case the weakest concave lens that affords the best vision will be the measure of the myopia. In the case under examination with concave lenses, the refraction of the eye is proven to be myopic.

AN ILLUSTRATIVE CASE OF ANISOMETROPIC HYPERMETROPIA.

A young woman, about twenty years of age, comes to an optometrist, complaining of asthenopic symptoms, that is, her eyes soon get tired and give out after she has used them for some time, and this is especially the case in the evening. She looks to be anæmic and in poor health. The bridge of the nose is flat, as are also the parts around the angle of the jaw. There is slight asymmetry of the face, the left half being apparently more and better developed than the right. No muscular insufficiency; the pupils are equally movable in each eye. The patient says the left eye is the best, a fact which seems to be corroborated by the appearance of the face.

The optometrist, therefore, examines this eye first, and finds the acuteness of vision to be equal to 20/20. This is normal vision, and excludes myopia or astigmatism; but still there is a possibility of the existence of hypermetropia, either manifest or in a latent form, that is, concealed by the action of the accommodation. Weak convex lenses are tried and are rejected; this proves at least that there is no manifest hypermetropia, but leaves open the question of the existence of latent hypermetropia. The record is made L. E. V. = 20/20.

The right eye is then examined, and the acuteness of vision found to be only 20/100. A trial with convex lenses results as follows: + 1 D. makes the same line of letters clearer and plainer, and some letters visible in the next line. This improvement continues with stronger lenses, until it is found that + 3 D makes vision equal to 20/40. This seems to be the correction for this eye; as + 3.50 makes vision worse. The record to be made in the case-book would read as follows: R. E. V. = 20/100 H. m. = + 3 D., with which V. = 20/40.

The youth of the patient indicates the probability of the existence of some latent hypermetropia in the left eye as well as in the right. This presumption is justified by the fact that both eyes are soon fatigued by close use, which is nearly always the case in hypermetropia. The optometrist then wants to determine whether or not there is any latent hypermetropia, and he asks, how can it be done? There are several methods—the use of atropine, the fogging method, the retinoscope, and the amplitude of accommodation. There are innumerable objections to the use of atropine by the optometrist, and the use of the retinoscope and the fogging method may for some supposed reason not be available.

In the absence of the information afforded by either of the above means, the optometrist will look to the near point and the amplitude of accommodation as being able to throw some light on the question. A person twenty years of age possesses an amplitude of accommodation of 10 D. and a near point of four inches. A hypermetrope of the same age will not possess the same amplitude of accommodation, and consequently will not be able to see as near. The presence of 1 D. of hypermetropia will diminish the amplitude of accommodation by that amount (10 D. — 1 D. = 9 D.) and will make the near point about four and a half inches. A hypermetropia of 2 D. means an amplitude of accommodation of 8 D. and a near point of five inches. A hypermetropic eye of 3 D. possesses only 7 D. of positive refraction, with the near point at five and a half inches.

Bearing these points in mind, the optometrist is able to use them to approximate the degree of ametropia present. In this case, the examination of the right eye shows the near point to be situated at six and a half inches, which indicates a hypermetropia of + 4 D.; and as the previous examination with test-lenses showed a manifest hypermetropia of 3 D., there remains a latent hypermetropia of 1 D. The near point of the left eye is found to be at four and a half inches, which means a loss of refractive power of 1 D., or a latent hypermetropia of that amount.

In this case it would be proper to order R. + 3 D., L. + .50 D.

And the use of these glasses would most probably cause all the symptoms of asthenopia to gradually disappear. It will be noticed that the glasses are not ordered sufficiently strong to entirely correct the total hypermetropia, because young persons usually possess such an excess of accommodation as to prevent its relaxation sufficiently to admit of a full correction being made.

The question occurs as to what to attribute the impairment of vision in the right eye, in spite of the correction of its hypermetropia. It is not due to the small size of the retinal images, because after the correction of the defect by glasses they are of the same size as those of an emmetropic eye. It is more probably due partly to a lack of development of the retina, and partly to a lack of use of the eye. The condition of a hypermetropic eye is essentially due to a lack of development of the organ, which affects the retina in such a way as to make it less sensitive. This places the right eye of this patient in a less favorable condition for use than the left, and therefore the individual has naturally preferred to use the better eye to the greater or less exclusion of the other, perhaps involuntarily without his own consciousness, the continuation of which only intensifies and perpetuates the trouble.

It is of great importance to this patient to cause her to bring her right eye into active exercise. She should, therefore, be advised to read or work half an hour twice each day with the right eye alone by the aid of her correcting lens, and at the same time the other eye should be closed.

TESTING FOR ASTIGMATISM.

The above practical case was introduced to illustrate the mode of procedure in the examination of an everyday case, and we now pass on to outline the further steps in the process of examination of a case of optical defect. If concave glasses do not improve vision, or improve it but slightly, it is proven to be not a case of myopia. We now have a case in which we have excluded both hypermetropia and myopia, and in further hunting for the cause of the impaired vision our next thought will be as to the existence of astigmatism.

To determine the existence of this defect, the patient's attention is directed to the astigmatic cards hanging on the wall, either the card of Pray's letters or the card of radiating lines. If some of the letters or some of the lines appear very much blacker and clearer than others, it is proof of the existence of astigmatism. The more important tests for astigmatism may be mentioned, as follows:

1. Ophthalmometer.
2. Chart of radiating lines.
3. Stenopaic slit.
4. Ophthalmoscopy.
5. Retinoscopy.
6. Cylindrical lenses.

The diagnosis of the presence of astigmatism in any case is one of the early questions which the beginner in optometry is ambitious to be able to decide, and therefore we feel justified in giving space to a description of the more important tests.

1. THE OPHTHALMOMETER.

This instrument is used to measure the curvature of the cornea in its several meridians by means of catoptric images viewed through a telescope. This telescope contains a bi-refrangent prism which causes a doubling of every object looked at. The objects of attention are two mires, which in the earlier instruments were movable. The more improved ophthalmometers have stationary mires, by which the same angle of reflection from mire to cornea is maintained, while in movable mires the angle varies with each move of the mire, thus introducing an element of inaccuracy.

The telescope is mounted on a movable tripod and is focused by moving or sliding it closer to or farther from the patient. In the later models the focusing is accomplished by a rack and pinion adjustment.

To meet the varying heights of different patients an adjustable chair is to be preferred, in addition to which the chin-rest can be raised or lowered as necessary.

The patient is requested to keep both eyes open and with the eye under examination to look directly into the tube. The instrument can also be adjusted for height by means of a screw post, and it is then focused so as to make the images of the mires sharp and distinct. The doubling causes four mires to be seen, but the two outer images in the periphery of the field are to be ignored and attention given to the two central images.

The mires are illuminated by light reflected from Welsbach mantles or electric lights, or by a small electric lamp back of the mires, the so-called "luminous mires."

The instrument is then rotated until the guide lines are continuous, and if this occurs in the horizontal meridian we choose this for the primary position, and then move the mires until they are in correct apposition. We revolve the instrument to the secondary position, which is always at right angles to the first, and the optometrist notes any change that may have taken place in the relative positions of the mires.

If the mires still maintain the same positions, the cornea is shown to have the same curvature in the two principal meridians. If the mires overlap in the secondary position there is astigmatism with the rule; if they separate, astigmatism against the rule.

In some instruments the amount of excess of curvature is shown by the overlapping of the steps, each step representing one dioptre. In other instruments the radius of curvature of each meridian and its equivalent value in dioptres can be read off a graduated wheel.

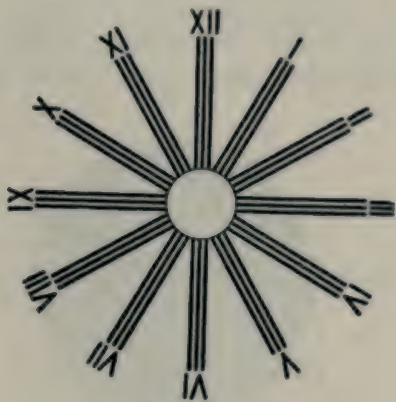
The ophthalmometer indicates positively the location of the two principal meridians of the cornea and the amount of difference between them, but on account of the possible existence of lenticular astigmatism, the ophthalmometric readings are not to be depended upon without confirmation.

2. CHART OF RADIATING LINES.

The "clock-dial" card is the one in most common use, consisting of radiating lines, at the extremity of each of which is a number in Roman characters, resembling the characters on a clock face, from which it derives its name. This is a subjective test, and reliance must be placed upon the patient's answers as to whether astigmatism is present or absent. If all the lines appear equally black and distinct, astigmatism may be excluded: but if one set of lines stands out as more or less distinct than the others, astigmatism is shown to be present. In high degrees of the defect, the interspaces are lost and the three lines appear as one.

In the use of this card there are two rules for the optometrist's guidance.

1. *The lines which are most distinct indicate the defective meridian.* For example, if the vertical lines appear most distinct, we know that the horizontal meridian of the eye is normal, be-



Astigmatic dial.

cause the vertical lines are seen by the horizontal meridian. Therefore it is the meridian at right angles (vertical) which is defective, and this corresponds to the distinct lines on the card.

2. *The axis of cylinder is in some directions as indistinct lines.* Referring to the example just mentioned, where the vertical meridian was defective, the cylinder is placed axis horizontal so as to bring its refractive power in front of the vertical meridian, and this horizontal position corresponds to the indistinct lines.

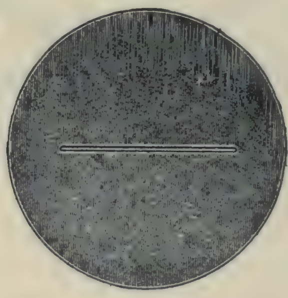
If the astigmatism is hypermetropic and not of high degree. it may be concealed by the action of the accommodation so as to make all the lines appear alike. In such a case the fogging system is of much value.

3. STENOPAIC SLIT.

This is a metal disk the size of a trial-lens, with a central slit or opening about 1 mm. wide. The purpose of the slit is to allow light to enter the eye only through one meridian. When placed at 90° we are testing the vertical meridian of the eye; when placed at 180°, the horizontal meridian. The slit is rotated slowly while the patient looks at the test-letters and is requested to note if vision becomes better or worse. If no difference is observed we assume that astigmatism is absent.

If there is a difference we know that astigmatism is indicated, and we rotate the slit to the position of best vision, and then to the position of worst vision, which will be at right angles to the first, and these will represent the two principal meridians.

After having located the two principal meridians in this way, the refraction of each is measured by spherical lenses placed in



front of the eye, while the slit is in its several meridians. There will be a difference in the refraction of the two meridians and such difference will represent the amount of astigmatism. For instance, if with the slit at 90°, vision equals 20/20 and is just as good with + .50 D., we assume that the vertical meridian is hypermetropic to the extent of .50 D. Rotating the slit to 180° the vision is reduced to 20/30, which is raised to 20/20 by + 1 D., we assume that the refraction of the horizontal meridian is hypermetropic 1 D. The amount of astigmatism is .50 D., and the correcting lens is + .50 D. S. ⁐ + .50 D. cyl. axis 90°.

Too much reliance should not be placed on this method without corroboration.

4. OPHTHALMOSCOPY.

In the use of the *direct method* of the ophthalmoscope, the presence of astigmatism is made evident by a difference in the clearness of the blood vessels running in different directions, or by a difference in the strength of the lens required to clear up the blood vessels in the vertical direction as compared with the horizontal, and the amount of astigmatism would be represented by the difference between the two lenses. The observer must remember that when he is measuring the vessels in one meridian, it is really the meridian of the eye at right angles that is being tested. For instance, if a + 1 D. was required to see the vertical vessels and a + 2 D. the horizontal, the case would be one of compound hypermetropic astigmatism, the refraction of the horizontal meridian being + 1 D., and of the vertical meridian + 2 D., and the correcting lens would be + 1 D. S. ⌒ + 1 D. cyl. axis 180°.

The shape of the optic disk is also changed in astigmatism, becoming decidedly oval.

5. RETINOSCOPY.

In the use of the retinoscope the presence of astigmatism is made evident by the band of light across the pupil, which is especially noticeable in the higher degrees of the defect.

The optometrist notes by the direction of the movement of the reflex whether the refraction is myopic or hypermetropic, and then he proceeds to use the indicated lenses for the purpose of neutralizing the movements. After neutralizing one meridian he turns to other meridians and, if in these movement is still noticeable, astigmatism is present The rule is to correct the meridian of least defect first, and then the meridian of greatest defect.

For example, if + 2 D. stopped the movement in the vertical meridian and + 3 D. in the horizontal, there is shown to be a hypermetropia of 1 D. and an astigmatism of 1 D. and the correcting lens would be + 1 D. S. ⌒ + 1 D. cyl. axis 90°.

6 CYLINDRICAL LENSES.

In the test with trial-lenses it is customary to commence with convex spheres; these may be readily accepted and thus prove hypermetropia; or if not, they should be compared with cylinders; the change being quickly made so that the patient can easily determine which is the better of the two. Convex cylinders are placed in the trial-frame with axis at 90°, and then slowly rotated in both directions in order to determine if there is any other position of axis that affords better vision. If astigmatism is really present, patient can readily determine if vision is made better or worse as the cylinder is rotated. If he says he can see no difference astigmatism is most likely absent.

If the rotation of the plus cylinder shows better and worse meridians, but still not clear in any position, and if the acuteness of vision is below normal, then concave cylinders may be tried, commencing with axis at 180° and rotating through the various meridians. It is understood that convex at 90° and concave at 180° corresponds to astigmatism with the rule, which is the most common condition, and therefore the most natural positions from which to start.

IMPAIRED VISION FROM OTHER CAUSES.

The optometrist now has examined his case for hypermetropia, myopia and astigmatism, and if either of these defects has been present, he has been able to detect its existence by following the above methods.

Sometimes in his work the optometrist will meet with a case in which neither of these defects exists, and in which he is unable to improve the vision by any glass or any combination of glasses. This, then, is probably a case of amblyopia from some cause; and here comes in the value of the use of the ophthalmoscope to determine the seat and cause of the impaired vision. It is most probably located either in the cornea, as spots, or deposits, or opacities of this membrane; or on or in the crystalline lens, incipient cataract; or in the retina or optic nerve, as retinitis, or neuritis, or atrophy. With a little practice and experience with the ophthalmoscope the optometrist is able to recognize which of these conditions is present, and is able to advise his patient intelligently as to what course to pursue in seeking medical advice. Or, if the optometrist does not possess an ophthalmoscope, he is able, by other means, to determine whether the defective vision is due to a refractive error or not, by following the methods above described; and if not, he would be justified in advising the patient to consult an oculist, as the case would then be one that needed medical attention.

METHODS OF RECORDING IMPAIRED VISION.

In testing distant vision, if the patient is unable to read even the largest letters at the top of the card when he is seated at the regular distance of twenty feet, he is asked by the examiner to arise and approach the card and to stop just as soon as the largest letter becomes legible. If he stops at fifteen feet, and says he can see the top letter on the card, which is numbered 200, then his vision is recorded by the optometrist as 15/200. If he must go up to ten feet or five feet before he is able to distinguish this top letter, his vision would be 10/200 or 5/200, respectively. In some cases of high myopia the patient is compelled to approach as close as two feet before he is able to distinguish the large letter at the top of the card, in which case the record would read V. = 2/200.

When the patient's sight is less than this, that is, when he is unable to read any letters at any distance, then the ability to count fingers is used as affording a sufficient test for all practical purposes. One, two or three fingers are held between the eye and the light, and the greatest distance at which they can be counted is observed and recorded in the optometrist's record-book. When fingers can no longer be counted, it is not usual to speak of vision, but only of perception of light; and this is distinguished as qualitative or quantitative.

The patient with qualitative perception of light will see and distinguish the outlines of any bright object, such as a sheet of white paper, when it is presented to him at a favorite angle, and will be able to recognize large, dark marks upon it, or, perhaps, can detect the difference between the white margin and the printed portion of the page. The patient with quantitative perception of light will be able to discern the lighter from the darker parts of the room, or, at least, will be able to point out the position of a flame, and will know when it is lowered or concealed. When perception of light is lost, the eye may be considered as beyond the reach of art, except in some very rare cases of glaucoma, where a timely operation will sometimes do wonders in restoring vision that is apparently hopelessly lost. In making a note in his record-book of those cases in which only perception of light exists, it is customary for the optometrist to write it as p. l.

POINTS OF IMPORTANCE IN THE EXAMINATION.

Several points in the examination of distant vision are of sufficient importance to require emphasis and reiteration.

The card of test-letters should be hung in such a position as to receive the best possible illumination, and at such a distance (twenty feet, if possible) as to exclude the need of accommodation.

Each eye should be tested separately, commencing, usually, with the right eye, or, in cases of marked anisometropia, with the eye that possesses the best vision, while the other eye is covered by an opaque metal disk placed in the trial-frame, or a frosted glass or a strong convex lens. This is a much better method to exclude the other eye than to allow the patient to close his lids, as he will either not close them completely, or else he will close them so tightly as to also unconsciously slightly contract the muscles of the eye under examination, in either of which cases the perfect result of the examination may be changed. Neither should he be permitted to cover the eye with his hand, as he may either look through his fingers or he may press on the eye so tightly as to momentarily interfere with the function of the retina, and thus again, in either case, vitiate the result of the examination.

In determining the refraction of an eye, the test of the distant vision with trial-lenses should always commence with convex.

After the refraction of each eye has been separately ascertained, the two eyes are then tried together, when it will be found that binocular vision (which means single vision with two eyes) is much better and more satisfactory than that of either eye separately. And this is even the case in persons of marked anisometropia (each eye differing in vision and in refraction); the vision of the best eye alone is not as good as the two eyes together, or, in other words, the vision of the good eye is improved by that of the poorer eye, strange as this may seem at first. It may be well to mention that there are some exceptional cases where the sight of the good eye is made worse by that of the poorer eye, and where vision is more satisfactory when the deficient eye is excluded.

THE OPHTHALMOSCOPE AS A METHOD OF EXAMINATION.

Ophthalmoscopy is at the same time one of the most important methods of examination, and one of the most difficult, for a clear view of the fundus can sometimes be obtained only by a skilful observer. It is not only of the greatest importance in the diagnosis of diseased conditions, but as a method of determination of the various forms of ametropia it is not to be despised.

The first step for a beginner is to familiarize himself with the appearance of the normal fundus, a very good representation of which is given in the colored plate. This is necessary, in order to be able to recognize a diseased condition when it is met with, and even after the optometrist has developed into an accomplished ophthalmoscopist, and able to easily detect morbid changes, there may still be considerable difficulty to interpret the significance of these diseased appearances.

Practice and experience are the best teachers, but the optometrist will be materially assisted in mastering this method by a careful study of the writings on this subject, together with colored plates of the fundus.

The ophthalmoscope was given to the scientific world by Helmholtz, in 1851, prior to which time the interior of the eye was as a closed and sealed book, and black as the proverbial "ace of spades." This, to the inquiring mind, raises the question as to why the interior of the eye is so dark, and why the pupil is black.

WHY DOES THE PUPIL APPEAR BLACK?

This may seem like a very simple question, and yet its answer depends upon a line of scientific reasoning that brought about the invention of the ophthalmoscope. The pupil of the eye appears black, because there are no rays of light passing from the eye of the observer to illuminate it. If a candle is held in such a way as to light up the pupil, the rays of light return to the candle, which is the source of light. If the observer attempts to intercept these return rays of light, and thus obtain a view of the interior of the eye, as soon as he undertakes to place his own eye in the path of these return rays, he at once shuts off the source of light and there are then no rays to return.

If now, by some means, the observer is able to send the rays of light from his own eye into the patient's eye, he will receive some of these rays back again, and then the pupil, instead of appearing black, will give a red reflex. The simplest manner in which this can be accomplished is by means of a piece of plate glass and a light placed at the side of the patient's head; by holding this glass up to his own eye the optometrist can reflect some light into the eye under observation, when the rays will return to the glass and pass through it into the observer's eye and afford a view of that part of the fundus from which these rays come.

Helmholtz improved on this by using three plates of glass, which might be called the original ophthalmoscope. In our present improved instrument the concave mirror throws many more rays of light into the eye, and the perforation allows a larger number of return rays to enter the observer's eye, and hence a better and brighter image of the fundus is secured.

In the use of the ophthalmoscope two methods of examination are employed: the *direct* and the *indirect*.

DIRECT METHOD OF EXAMINATION.

The room should be darkened, and the light placed on the same level as the eye that is to be examined, and on the same side of the head, and some few inches back of it. The optometrist sits by the side of his patient and facing him, using his right eye to examine patient's right eye, and *vice versa*.

The pupil is then illuminated by the concave mirror of the ophthalmoscope, held ten or twelve inches away, when the red reflex is obtained, and if there are any opacities in the cornea, crystalline lens or vitreous, they will become distinctly visible as black spots on a red background. The instrument is then moved slowly toward the patient, all the while keeping the pupil well illuminated, until the mirror is as close as spectacles can be worn and the foreheads of optometrist and patient are almost in contact, when the retina and optic nerve and the blood vessels come into view.

This method of examination of the fundus of an eye allows but a small portion to be seen at one time, but as it is magnified fifteen diameters the minutest details are perceptible. The accommodation of both optometrist and patient should be relaxed, and then, if both eyes are emmetropic, a perfect picture of the retina of the observed eye will be formed on the retina of the observer's eye.

WHAT TO LOOK FOR.

The red color of the fundus is due largely to the blood vessels of the choroid. The color varies in different persons, and in different parts of the retina in the same individual, being most pronounced at the posterior portion. The fundus is darker in brunettes than in blondes, on account of the preponderance of pigment matter in the former. The deeper color at the posterior portion of the eye is most noticeable in the region of the yellow spot and optic disk, and around the latter is oftentimes a black ring, known as the *choroidal ring*.

The optic disk, that is, the entrance of the optic nerve, is the chief land-mark looked for in the examination of the fundus, pre-

senting a delicate grayish-red tint, the nasal side being of a little deeper color than the temporal. The disk is not always perfectly circular, but may be slightly oval, elongated either horizontally or vertically. The yellow spot is situated at the same level, and a little to the temporal side of the disk.

The retina receives its blood supply from the arteria centralis retinæ, which enters the eye in the optic nerve and divides into branches that spread out over the whole fundus and carry the blood to every portion of it. These arterial branches all have their accompanying veins, which collect the blood and converge into one large vein which enters the optic nerve near where the artery emerges. The arteries are lighter in color than the veins, with a light band or reflex along their center. The veins are larger and darker and somewhat more tortuous than the arteries.

DETERMINATION OF MYOPIA.

In myopia the retina is situated too far back, and the rays of light proceeding from it are convergent, and will focus at the location of the far point. Such rays cannot be focused on the retina of an emmetropic observer, and hence the picture of the fundus received will be blurred and indistinct, the disk appearing larger than normal. A suitable concave lens rotated into the sight hole of the ophthalmoscope will render the convergent rays parallel and clear up the retinal picture. The amount of the myopia will be determined by the *weakest* concave lens which affords a distinct view of the fundus. It would be very easy for the examiner to see with a stronger concave lens, by allowing his accommodation to come into play, which it has a constant tendency to do, but this would interfere with the accurate measurement of the myopia.

DETERMINATION OF HYPERMETROPIA.

The rays emerging from an hypermetropic eye are divergent, and cannot be focused upon the retina of the observer's eye, except by an effort of his accommodation, or by the intervention of a convex lens. If the defect be not too high a degree there is every incentive for the accommodation of the observer to exert itself and correct the defect, and make the retinal picture distinct: but it would be impossible in this way to measure the amount of accommodation used, and hence no indication of the degree of hypermetropia would be afforded. But the accommodation must be relaxed and a convex lens found which will render the diverging rays parallel. When an emmetropic optometrist is examining ophthalmoscopically an eye that is hypermetropic to the extent of 3 D., he must rotate a convex lens of the same number into the aperture of his instrument, which will afford a clear view of the fundus and represent the degree of hypermetropia.

The temporal side of the disk is the easiest part to bring into focus for the beginner, and can be used for these examinations, together with the small blood vessels as they pass from it to the yellow spot.

DETERMINATION OF ASTIGMATISM.

In the use of the ophthalmoscope astigmatism may be suspected when the appearance of the fundus is more or less blurred, and when spherical lenses fail to entirely clear it up; besides which the disk is no longer round, but appears oval. In this defect the refraction of the several meridians of the eye is determined by the use of convex and concave spherical lenses focusing the blood vessels that run in the meridians at right angles.

For instance, the strongest convex or weakest concave lens is found that gives the clearest image of the blood vessels running horizontally from the disk to the yellow spot, and this lens will indicate the refraction of the vertical meridian of the eye. In like manner the lens is selected that is required for the vessels passing vertically upward and downward from the disk, which will indicate the refraction of the horizontal meridian. With the refraction of the two chief meridians known, it is a simple matter to estimate the character and degree of astigmatism present. The refraction of the oblique meridians can be determined in the same way.

THE INDIRECT METHOD OF EXAMINATION.

In this method the ophthalmoscope is held at ordinary reading distance (twelve to fifteen inches), and the fundus is viewed through a strong convex lens placed within its focal length from the eye, and held in position by the thumb and index finger. The rays of light proceeding from the patient's eye pass through this convex lens and are refracted by it, forming a real inverted image of the fundus in the air in front of the lens, and the observer, looking through the aperture of his ophthalmoscope, gets a clear view of this image. It is important that the convex lens be placed within the focal distance of the lens.

The advantages of the indirect method may be mentioned as follows:

1. The optometrist is farther away from his patient, which makes the examination easier, and is of obvious advantage in other ways.

2. A larger extent of surface of the fundus can be seen at one time.

3. There is no necessity for the employment of correcting lenses in the ophthalmoscope.

4. It is possible to obtain a view of the fundus through a smaller pupil.

The advantages of the direct method are that the image is erect and the details of the fundus very much more magnified, and consequently any departure from the normal condition can be more easily detected.

RETINOSCOPY, OR SHADOW TEST.

This method of estimating the refraction of an eye is especially useful in the examination of children, or of other persons, on whose answers entire reliance cannot be placed, and it is always valuable as an auxiliary test in any case. While it seems a little difficult at first sight, it becomes fairly easy after a little practice, and on account of the rapidity and accuracy with which it can be performed, it is regarded as the best objective test at the command of the optometrist.

The examination is conducted something after the same manner as the indirect method of the ophthalmoscope, without the interposition of any convex lens. The light should be directly over the patient's head, and the optometrist is seated at a distance of one meter, or a little more. The mirror used may be either plane or concave, according to the fancy of the observer. The light is reflected into the eye, when the red reflex is at once noticed in the pupil. As the mirror is rotated in various directions the light passes off and is followed by a shadow, the direction of the movement of which determines the kind of refraction that is present.

When a plane mirror is used, and the shadow travels across the pupil in the *same* direction as the mirror is rotated, the indications are that the case is either one of emmetropia or hypermetropia. Convex lenses are then used in increasing strength until one is reached that reverses the movement of the shadow. In emmetropia a + 1 D. lens will accomplish this.

If the plane mirror is used, and the shadow moves across the pupillary space in the *opposite* direction to which the mirror is rotated, the existence of myopia is indicated, when concave lenses of increasing strength are used until the movement of the shadow is reversed, and the lens thus found will be the measure of the defect.

The vertical and horizontal meridians can be examined in this way, and if they are both found to be alike, the case is one of emmetropia, hypermetropia, or myopia; but if there is a difference in the refraction of the two meridians, astigmatism is present, the degree of which is represented by the amount of that difference.

With a concave mirror the movements are just the reverse of those given above, that is, in emmetropia and hypermetropia the shadow travels *against* the rotation of the mirror, and in myopia *with* it.

A dilated pupil is of advantage in retinoscopy, as is also a relaxation of the accommodation. If the pupil is small it greatly increases the difficulty of seeing the shadow.

AN ILLUSTRATIVE CASE.

A mother brings her young daughter to the optometrist, with the statement that she cannot read or see close at hand, although her distant vision is as good as ever. She is about fifteen years of age, and is pale and weak, and her mother says she is just recovering from a severe attack of diphtheria, and is now gaining in strength every day. Previous to her illness her sight had always been fairly good, and this impairment of near vision has only been noticed since her recovery from the diphtheria.

This sudden appearance of difficulty in near vision reminds the optometrist of the action of atropine, while the preservation of normal vision at a distance is another point of similarity to the effect of this drug. Now it is well known that atropine acts by paralyzing the accommodation, and hence the optometrist is justified in presuming that the case in hand is one of paralysis of the accommodation. The good distant vision proves that neither myopia nor amblyopia is present.

When a young person of this age complains of inability to read as close as eight inches, the optometrist should first ascertain the acuteness of vision; if this is markedly impaired, he would think of the possible existence of myopia or amblyopia. The former can be determined by trial with the concave lenses, and the latter by the pin-hole test.

But in the present case the distant vision is good, and the question to be solved is, "What is the cause of the impairment of near vision?" It is due to one of two causes—either paralysis of the accommodation or hypermetropia. In the latter case the defect may be of such a degree that all the power of the accommodation is needed to correct the refraction and afford satisfactory distant vision, and there is not sufficient power of accommodation left to bring the rays from near objects to a focus on the retina. But, again, it should be remembered that if an individual was so strongly hypermetropic, there would be some impairment of sight, and distant vision would no longer be perfect. By this manner of reasoning, and by a process of exclusion, the optometrist can scarcely come to any other conclusion than that the present case is one of paralysis of the accommodation.

Paralysis of accommodation in a youth is the same condition as presbyopia in an old person; in the one case it is due to disease, in the other to age. A man fifty years of age, whose distant vision is good, but who finds difficulty in reading and writing, is probably an emmetrope, over whom presbyopia is just beginning to steal. There may be a very slight degree of hypermetropia present, but the supposition of hypermetropia becomes less probable the older the individual grows without the need of glasses for reading. Hypermetropia often shows itself as an early presbyopia, and a hypermetrope will begin to feel the need of glasses at thirty-five, or soon thereafter; so that in a man who has reached the age of fifty without wearing glasses, the presence of hypermetropia can almost certainly be excluded. An individual, on the other hand, in whom both distant and near vision are greatly impaired (and in the absence of amblyopia) is most likely hypermetropic, and, in a degree, the stronger as the patient is younger and the far point is further removed.

Patients who say they can see well to read, but cannot see well at a distance, are probably myopic, while those who cannot see well, either near or far, either with or without ordinary spherical glasses, are probably astigmatic.

In the case at hand there is another point that will help toward making up the diagnosis, and that is the condition of the pupils, the contraction and dilatation of which go hand in hand with the use or rest of the accommodation. In the young lady under examination the pupils are very much dilated. On exposure to light they contract very slowly, and on alternately covering and uncovering the eyes it is seen that they react very slowly and imperfectly to the light.

It may now be regarded as certain that the diagnosis previously made is correct, and it remains to determine the degree of the affection; that is, whether the paralysis of the accommodation is partial or complete.

In testing the patient, the optometrist finds the vision without glasses to equal 20/20. He then proceeds to make a trial with convex lenses, and he finds she can still read the No. 15 line with + 3 D., but not with + 3.50 D.; we have therefore H. m. = + 3 D., V. 20/15. The partial correction of the defect by means of the accommodation is incomplete, as the patient is able to read only the No. 20 line. In the eyes of hypermetropes, where the rays are not sharply focused on the retina, there occur instead circles of diffusion. These are not sufficiently great to render the No. 20 line illegible, but they do make more diffuse the smaller characters of the No. 15 line.

The optometrist tries the feeblest convex lens which affords the patient her greatest acuteness of vision, 20/15, which is found to be + 1 D. She had previously read the same line with + 3 D., and her amplitude of accommodation is therefore the difference between the two = 2 D., instead of 12 D., which is the normal amplitude of accommodation for a person of her age, which means a loss of 10 D.

In determining the glass to be prescribed for reading and writing at twelve inches, the optometrist will order the *weakest* convex lens that enables her to read at that distance; he chooses the weakest lens so as to require the accommodation to do part of the work and thus keep it in continual exercise.

To see at twelve inches requires a positive refraction of 3 D. (twelve inches = 30 C. M. 100/30 = 3 D.) A hypermetrope of 3 D. without accommodation would require the amount of his defect added to this: 3 D. + 3 D. = + 6 D. But as this patient still possesses 2 D. of accommodation, it should be subtracted from the 6 D., which leaves + 4 D. as the proper lens to be prescribed for reading at twelve inches.

ANOTHER ILLUSTRATIVE CASE.

The next patient that may apply to our embryo optometrist is an old gentleman seventy years of age. We will listen to the old man's story, and give our friend some assistance in fitting the case. The complaint is that the glasses that have been used for so many years with comfort are no longer satisfactory. On questioning the patient, we find that he did not begin the use of glasses for near work until he was fifty-five years old. This at once raises the suspicion in our friend's mind that his patient may have been somewhat myopic, for he knows that in emmetropes presbyopia (and with it the need of glasses) usually steals over the patient about the age of forty-five. He also knows that in hypermetropia it appears earlier, and in myopia later.

The first step in the examination of any case is to determine the refraction and ascertain the acuteness of vision; and our friend therefore asks his patient to be seated at the proper distance and to look at the test-card hanging on the wall, and to tell him which line he is able to read, as he first excludes one eye and then the other. With the right eye he distinguishes only the No. 80 line, and with the left eye the No. 25 line; and as the card is hanging at a distance of twenty feet, our friend writes the record in his book as follows: R. E. V. = 20/80, L. E. V. = 20/25. The vision of the right eye is markedly deficient, and on first thought it would seem as if the vision of the left eye was also below the standard. But our optometrist remembers what he has read in a former chapter of *The Optometrist's Manual*, that the visual acuteness gradually diminishes with advancing years. This is due to a loss of the positive refracting power of the eye, which diminishes rapidly after the age of fifty, the emmetrope becoming hypermetropic, the hypermetrope more hypermetropic, and the myope becoming emmetropic, or, possibly, hypermetropic. The vision of this eye, therefore, indicates emmetropia, but we will whisper in our friend's ear that emmetropia at this age does not exclude the possibility of myopia at fifty years, but only that this eye seems to have normally undergone the usual changes accompanying advancing years. In fact, it may be considered as altogether probable that a slight myopia (perhaps 1 D.) did exist, and that it was neutralized by the loss of refraction and passed over into emmetropia, as is usually the case.

The optometrist now examines the glasses the patient has been using, and finds them to be + 2.25 D., and he expresses his surprise that the patient should have been able to use these (rather weak) glasses for so long a time. He says he can read large letters with them for a short while if he has a very good light, but he cannot continue reading for any length of time. On being asked to show how he reads, it is noticed that he holds the book at a great distance from the eyes, and prefers to place the lamp between his eyes and the book. With his + 2.25 D. glasses he is able to read at a distance of sixteen inches for a little while.

Although the patient does not know the reason why, the lamp is placed in the position mentioned so that its strong light will fall upon the pupils and contract them, and in this way shut off the circles of diffusion, which would otherwise disturb vision. These diffusion circles are caused by the letters not being accurately focused on the retina, because of the lack of refractive power in the eye itself, and because of the insufficiency of the spectacle lenses that are worn to assist the eye; and the more of these diffusion circles that can be excluded, the clearer will be the vision.

The patient is asked at what distance he would like to read, or at what distance he is accustomed to read. He replies that of necessity he has been compelled to read at arm's length, but that he would like to read at a distance of about twelve inches, and he wants to be able to read for any length of time and without discomfort. To be able to read at twelve inches without fatigue requires a positive refracting power of 3 D. (as shown in the previous case above).

A careful examination shows that it is only the left eye that is able to read at the distance mentioned, the right eye, on account of its diminished acuteness of vision, not being able to participate in the act of reading. An ophthalmoscopic examination of this eye reveals an incipient cataract, which explains the defective sight and which precludes the possibility of any benefit from glasses.

ANOTHER CASE.

The next patient is one that at once impresses the optometrist as being a myope. He wears glasses which are easily seen to be concave; his head is thrown back in the air, and his eyes are large and prominent. He says he has two brothers and a sister who are near-sighted, and another sister who is not. He has never been able to see well at a distance, and he has sometimes used his brother's glasses.

On being asked if his parents are near-sighted, he replies in the negative, and he refers especially to his father as having had good sight, since he was seventy years old before he was required to use glasses, and he was always able to read the finest print. This, to the optometrist's mind, is sufficient evidence of the existence of myopia, as no person of that age and of any other refraction would be able to read without glasses.

The glasses the patient is wearing are found to be — 6 D., and he says they were fitted by an excellent optometrist and are the best that could be found. He boasts of his eyes as being strong, says he has no disease of the eyes, is able to see the smallest objects, and can read the finest print; but complains of neuralgic pains which shoot through his eyes and forehead, but which he is hardly prepared to believe arise from his glasses.

A book of fine print is then handed to the patient and he is asked how far away he is able to read the print, which distance is found to be eight inches, and which the optometrist knows corresponds to a myopia of 5 D.

On the distance card he is unable to read even the largest letters. As the reading test indicates a myopia of 5 D., glasses of this strength are placed before his eyes, and he is able to read the No. 30 line, and his vision is 20/30. A weaker concave lens is not nearly so good, and a stronger concave lens does not enable any more letters to be read, although it seems to make vision a little better. We, therefore, conclude that the myopia is equal to 5 D., and the examination of the other eye yields the same result.

The optometrist now concludes that the patient has worn glasses that are too strong by 1 D., which have undoubtedly fatigued his eyes on account of the effort of accommodation required to overcome them. As he grows older the accommodation becomes weaker, and it becomes less and less able to overcome the too strong lenses, until finally the fatigue and discomfort become intolerable and the patient is forced to the conclusion that something is wrong.

In any case where it is impossible to raise vision to 20/20 by spherical lenses, there is always a suspicion of astigmatism, and our optometrist now proceeds to examine for that defect. The card of radiating lines is placed on the wall, and each eye is examined separately with the — 5 D.

In the examination and correction of our illustrative case, the optometrist is led to suspect the existence of astigmatism, and proceeds to examine for that defect by directing the patient's attention to the card of radiating lines hanging on the wall while the patient wears the — 5 D. lenses, which were previously found to be strong enough to correct his myopia. After a little hesitation he says he sees distinctly only the line on the right side at 10°, while all the other lines are more or less indistinct, especially the one perpendicular to this, which is 100°. This, therefore, indicates astigmatism and gives the direction of the two principal meridians, one at 10° and the other at 100°. The optometrist knows that the refraction of the latter meridian is — 5, because the lines at right angles to this were seen clearly by a spherical lens of 5 D.

In order to determine the refraction of the other principal meridian, the optometrist places over the — 5 D. spherical a convex cylinder with its axis at 100°. This at once blurs the vision, and he then tries concave cylinders with axes at same meridian. This at once improves vision, and after a little trial he finds that — .75 cyl., axis 100°, affords the most satisfactory vision, makes all the radiating lines appear equally clear, and raises the acuteness of vision to 20/20.

The correcting lenses for this case appear to be — 5 spherical combined with — .75 cylinder, but the optometrist will find on trying both eyes together with the cylinders and weaker sphericals that — 4 affords almost as good vision as — 5; and as the rule in myopia is to prescribe the weakest lenses, he orders — 4 S. $\bigcirc$ — .75 cyl., axis 100°. These glasses are advised for distance, and perhaps would also answer very well for reading for some years yet; but as our optometrist wants to avoid all cause of strain of the accommodation, and place the eyes under the most favorable conditions for use, he gives a weaker glass for reading, and orders — 2 S. $\bigcirc$ — .75 cyl., axis 100°. "These glasses give the greatest satisfaction," was the report when the patient returned some time after.

In describing these illustrative cases, we have endeavored to make them so plain and simple that the beginner in optics would readily be able to follow each step and understand the *rationale* of it; and no optometrist can carefully read them without gaining much practical information. We will conclude this series of practical examples in the determination of refraction, accommodation and visual acuteness with

ONE MORE ILLUSTRATIVE CASE.

This is a young man fifteen years of age. His sight has always been poor both at a distance and close at hand, and although he has tried to get glasses, he has never yet been able to find any which would improve his vision very much. He has just commenced his college course and taken up special studies in mathematics, and now the deficiency of sight is becoming a serious obstacle. He is unable to see the charts on the wall as the other students do, and he finds the greatest difficulty in making the correct geometrical drawings. On a general inspection, nothing abnormal is noticed about his eyes; they look perfectly natural, and any one would infer their possessor enjoyed good sight. But our optometrist notices an asymmetry of the face which is quite evident to a careful observer.

The reader who has carefully followed our description of the case so far will instinctively think of astigmatism as possible cause of the trouble, for the following reasons: Imperfect vision both near and at a distance, inability to be suited with the ordinary spherical glasses that are kept in stock at the stores. difficulty in making exact mathematical drawings, and asymmetry of the features of the face, all of which are symptoms of astigmatism.

Following out this suspicion, our optometrist proceeds to examine the eyes according to the rules already given. The right eye is able to read the letters on the No. 100 line with considerable difficulty, and if he attempts to name the letters on the next line he makes some amusing mistakes. He confounds letters which have no resemblance to each other, and sometimes is able to distinguish a complicated letter while he is unable to make out a very simple one by its side.

Convex glasses are first tried, in accordance with the proper routine of making an examination of the acuteness of vision, and it is found that + 1 D. improves the sight and raises the visual acuteness to 20/70, which cannot be improved any further by convex glasses, as stronger ones begin to blur and dim the letters.

With this + 1 D. lens before his eye the patient's attention is directed to the card of radiating lines hanging on the wall. He sees only the vertical line distinctly, and even that is not perfectly black; all the other lines are confused and ill-defined. Our optometrist now adds a + .50 cylinder with its axis in the direction of the line which is least distinct and at right angles to the line which appears clearest. He knows that the vertical line is seen by the horizontal meridian of the eye, and the horizontal line by the vertical meridian; and when he places the cylinder with its axis in the direction of the line which is least distant (that is, + .50 cyl., axis 180°) he adds to the refraction of the vertical meridian in the effort to improve the horizontal lines. This, however, makes vision worse and the lines appear to be more confused. The inference to be drawn from this is that the vertical meridian is not hypermetropic, because the horizontal line is not improved by the + 1 spherical and is made still worse by the + .50 cyl., axis 180°.

The optometrist now very properly rotates the cylinder before the eye in the endeavor to find a position in which the lines will be improved and made to appear more nearly alike. When the cylinder is rotated at right angles to its present position (that is, at 90°), the vertical line is made still more distinct than it was with the spherical alone. The inference to be drawn from this fact is, the horizontal meridian is still more hypermetropic than 1 D. The optometrist now tries stronger and stronger convex cylindrical glasses with their axes in the same meridian, with the result of making the vertical line still more distinct, the other lines also becoming clearer. Finally he reaches + 4 D. cyl., axis 90°, which seems to be about the strongest convex cylinder the eye will bear, with which all the lines seem quite clear except the horizontal one.

With this combination (+ 1 D. spherical combined with + 4 D. cyl.. axis 90°) the acuteness of vision is raised to 20/40. This is certainly a very great improvement over that obtained by the spherical alone, and yet our optometrist must not be content with that; in fact, he would not do his whole duty unless he made an effort to raise the acuteness of vision still higher, because he must know that the vertical meridian is not properly corrected or the horizontal line would appear as clear as the vertical.

Up to this point the vertical meridian of the cornea appears to be hypermetropic 1 D., which is the strength of the spherical lens first placed before the eye; but the dimness of the horizontal line proves that this 1 D. is not the proper correction for this meridian, and an effort must now be made to ascertain how it can be improved.

Perhaps this meridian may be emmetropic, and perhaps all the defect is in the horizontal meridian. With the sphero-cylinder now before the eye (+ 1 D. sph. ⊂ + 4 D. cyl., axis 90°) the horizontal meridian is corrected by + 5 D. and the vertical meridian by + 1 D. If our optometrist wishes to determine if the vertical meridian is emmetropic, that is, if he wishes to correct only the horizontal meridian, he removes the above sphero-cylinder and replaces it with a plain cylinder, + 5 D. cyl., axis 90°, with which the lines are seen pretty much as they were before, or perhaps a shade clearer. The inference to be drawn from this is that the vertical meridian is neither hypermetropic nor emmetropic, and the suspicion is very properly raised that it may be myopic.

In order to determine whether this meridian is myopic, concave cylinders are used and placed in the trial-frame with their axes horizontal or at 180°. A — .50 cyl., axis 180°, is added, and the vision is at once very markedly improved and the horizontal line made very much clearer. A — .75 cyl., axis 180°, produces still further improvement and makes the horizontal line appear as clear as the vertical. This makes a cross-cylinder, + 5 D. cyl., axis 90°, combined at right angles with a — .75 cylinder (+ 5 D. cyl., axis 90°, **L** — .75 cyl.), which raises vision to 20/20.

This case, therefore, proves to be one of mixed astigmatism, with a hypermetropia of 5 D. in the horizontal meridian and a myopia of .75 D. in the vertical meridian, and is corrected by the above formula. Mixed astigmatism may also be corrected by a sphero-cylinder, or, in other words, this cross-cylinder may be reduced to a sphero-cylinder as follows: — .75 D. S. ⊂ + 5.75 D. cyl., axis 90°.

The impairment of the acuteness of vision by this degree of astigmatism is very great, while the restoration of vision by the proper combination of lenses is highly satisfactory, and is one of the most agreeable experiences with which the optometrist can meet. An original vision of 20/100 is raised to 20/20 after correction, and a new world is opened up to the hitherto unfortunate patient. Surely this is a wonderful achievement for scientific optics.

It is a very interesting fact that this patient's mixed astigmatism can be converted into a case of simple astigmatism by calling his accommodation into action. In such a case the exercise of the accommodation corrects the 5 D. of hypermetropia in the horizontal meridian, while at the same time it increases the myopia in the vertical meridian to the same degree ($5 + .75 = 5.75$), and, therefore, the case is now corrected by — 5.75 cyl., axis 180°. This affords a normal degree of vision (V. = 20/20), but it imposes a great tax on the accommodation, and would soon cause symptoms of asthenopia if the patient used such a glass.

Another interesting fact about this case is that the patient can neutralize his astigmatism and raise his vision to the normal standard by applying the tip of his finger on a point of the eyeball upward and outward, the pressure exerted on this point being in the direction of one of the principal astigmatic meridians.

The subject of mixed astigmatism and its correction by crossed cylindrical lenses has always been considered a difficult and complicated one, and rightly so. The subject will be more fully considered in the chapter on astigmatism, but the preceding remarks will be of much practical value in pointing out one of the methods of the detection and correction of this defect.

RECAPITULATION.

This concludes the examination of distant vision, or, in other words, the testing of the acuteness of vision. It is a matter of the greatest importance to every person, especially to those whose occupation requires a continued use of the eyes (and what occupation or business does not require a constant use of these organs?), to be informed of the exact state of affairs with regard to his acuteness of vision. The educated optometrist must be competent to make the necessary examination, and he stands prepared to furnish this information to any and all who desire to know the state of their vision and who seek his skill.

There is but one way in which this knowledge can be gained, and that is for the individual to apply to a skilled optometrist who is competent to subject the eyes to certain tests which he knows can be relied upon. If they can pass these tests successfully, it will be a source of no little satisfaction for the patient to know that all is right.

If, on the other hand, the eyes are unable to measure up to the standard as required by the test, it indicates that something is wrong. The degree of departure from normal vision is ascertained at the same time, and the patient is thus warned that his eyes need attention and assistance in order to avoid a possible failure of sight.

The patient's vision is either normal and up to the standard, or it is abnormal and below the standard.

Normal Vision, or a vision of 20/20	means	Emmetropia or possibly Hypermetropia.
Subnormal Vision, or a vision below 20/20	means	Hypermetropia. Myopia. Astigmatism. Amblyopia. Spasm of Accommodation. Opacities of some of the Media. Organic Disease.

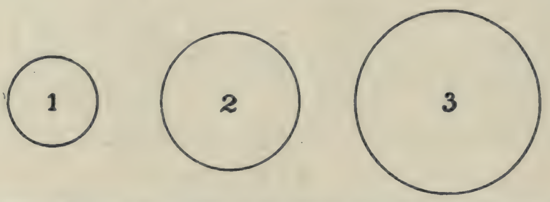
TESTING THE ACCOMMODATION.

After having ascertained the acuteness of vision and determined the refraction of the eye under examination, the optometrist naturally passes on to estimate the accommodation and to test the eye for vision close at hand as compared with that at a distance.

For this purpose the near type is used, or reading matter with types of different sizes, with which to ascertain and determine the near point and far point at which any particular line or size of type can be read.

Some authorities object to the employment, for this purpose, of bits of reading matter, for the reason that reading is not a certain proof of visual acuteness. They say, and with much reason, that persons who are accustomed to reading are able to guess at the majority of the words by their general aspect and by their relations to neighboring words, while those who are but little educated and unaccustomed to reading must decipher the letters one by one, and are, therefore, relatively in more unfavorable conditions while undergoing this examination than the former.

They say, further, that if we wish to determine the acuteness of vision at short distances, we should use isolated letters constructed on the same principles as the larger test-types. It is also evident that we must make the examinations always at the same distance, in order to obtain results exact and comparable. This examination would then be based on the same principle as that at a distance, namely, on the equality in the size of the retinal image.



Relative differences in the size of the retinal images of, 1, emmetropia; 2, corrected hypermetropia; 3, myopia of 4 D.

A second point, and a most important matter, is that the vision near at hand is very different in the different states of refraction. We will take, for example, a distance of ten inches. The young emmetrope will see at this distance with the aid of his accommodation, while the hypermetrope and the presbyope will also be able to see with the aid of convex glasses of greater or less strength, according to the power of their accommodation and the degree of their ametropia. The myope whose far point is at a distance greater than ten inches will, likewise, have need of a slight effort of accommodation. Only a myope of 4 D. will be able to see at a distance of ten inches without any effort of accommodation and without any correcting glasses. Degrees of myopia greater than 4 D. will require the use of concave glasses for seeing at the same distance.

It is obvious, therefore, that vision under these circumstances is attended with notable differences in the size of the retinal images. It makes no difference if the same test-letters are employed and if they are placed at exactly the same distance; the emmetrope, who accommodates, will still have retinal images smaller than the presbyope or the hypermetrope, who uses glasses, and the hypermetrope smaller images than the myope of 4 D. The result is, therefore, vitiated, as the size of the retinal image is changed in each case.

There is a method (by testing the eyes at a fixed distance with a convex lens of the same focal distance) by which it is possible to obtain in near vision the same advantages as in distant vision; that is, equality in the size of the retinal images, exclusion of the accommodation, and simultaneous determination of the refraction and of the accommodation and visual acuteness. But it is a very difficult matter to exclude the accommodation in near vision, even by the aid of a strong convex lens, except by the employment of atropine; and, consequently, this method of testing the vision is not generally employed in practice, and, therefore, we will not devote any space to a description of it.

In contrast to this method we have the reading types, which are in extended use and which serve every practical purpose, because all the optometrist desires is to be able to make such an examination as will enable him to prescribe those glasses which will allow the patient to use his eyes and do his work with comfort.

AMPLITUDE OF ACCOMMODATION.

The nearest point at which the reading matter can be distinguished, that is, the closest point for which the eye can accommodate itself, is called the *near point*. When the eye is in a condition of perfect repose and its accommodation entirely relaxed, it is then adjusted for the greatest distance at which it is able to see, which is called the *far point*, which, in emmetropia, is said to be at infinity.

(The hypermetropic eye is adjusted for a point beyond infinity, which means it is adjusted for rays converging toward its far point. The myopic eye has its far point at a certain fixed distance in front of it, and its dioptric system is adjusted for that distance.)

For practical purposes and in every-day examinations of the accommodation of the eye, the optometrist can call that point the far point which is at the greatest distance at which the reading type can be distinguished.

The distance between the near point and the far point is called the *range of accommodation*. It is the distance over which the eye has command by the aid of its accommodation. The force necessary to change the eye from its far point to its near point is called the *amplitude of accommodation.* Therefore, the amplitude of accommodation is represented by the difference between the refraction of the eye when in a state of complete rest and when at its maximum of accommodation.

The action of the accommodation in focusing the eye for its near point is of the same effect as a convex lens which would enable an eye, deprived of its accommodation, to see at the same point, and, therefore, the strength of the accommodation can be expressed by the number of this lens. In other words, it may be said that the accommodation is equal to a convex lens of such a strength as would give to rays coming from the near point a direction as if they came from the far point.

In view of the fact that the accommodation is equal to a convex lens of such power as to give rays coming from the near point a direction as if they came from the far point, the question naturally occurs, what will be the strength of such a lens?

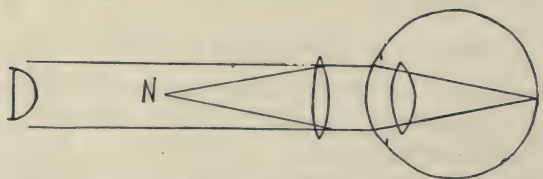


Diagram of an emmetropic eye, showing its adaptation for parallel rays, and the action of a convex lens in making divergent rays parallel.

An emmetropic eye, with its far point at infinity, is adapted for parallel rays proceeding from *D,* as shown in above diagram. In this condition of the eye no other rays but parallel can be focused on the retina. Rays proceeding from any other point, as *N,* must be rendered parallel before they can be united at the proper point on the retina.

Now every student of optics knows that parallel rays passing through a convex lens are brought to a point at the principal focus of the lens; and conversely, the divergent rays proceeding from the principal focus of the lens will emerge from it parallel. Therefore, if we place in front of this emmetropic eye a convex lens whose focus would be at *N*, it would render the rays proceeding from N parallel, or just as if they came from D. The eye, therefore, by the aid of this convex lens will see as well at the near distance N, as it does without the lens at the far distance D.

From the above facts the following rule is deduced: For the emmetropic eye the focus of the lens coincides with the near point, in order that it may render parallel the divergent rays proceeding from that point. Its focal distance is therefore equal to the distance which separates the near point from the eye. If this distance is twenty-five centimeters, the lens will have a refracting power of $100/25 = 4$ D., and the amplitude of accommodation will be equal to 4 D.; or, if the distance is measured in inches, it will be found to be at ten inches (which is equivalent to twenty-five centimeters), which means a refracting lens of one-tenth inch (which is equivalent to 4 D.).

The exercise of this power of accommodation serves to adapt the eye for points situated nearer than infinity. In order to determine the amplitude of accommodation of an emmetropic eye, we have only to find the nearest point at which the patient is able to read the smallest sized type. The distance of this point is the focal distance of the lens corresponding to (and expressing) the amplitude of accommodation.

This may be expressed in inches if the optometrist is accustomed to use the inch system of numbering lenses. If, then, the distance of this point be ten inches, the amplitude of accommodation will be equal to a convex lens of 1/10 inch focus.

If at eight inches, to a convex lens of ⅛ inch focus, and so on.

If, on the other hand, the optometrist is familiar with the dioptric system of numbering lenses, he will measure the distance of this near point in centimeters, as marked on his metric rule. The division of one hundred by this figure will give the strength of the lens, numbered in dioptres, which in an emmetropic eye expresses the amplitude of accommodation (and also its positive refracting power). For instance, if the near point be found at 20 centimeters, the amplitude of accommodation will be 5 D. ($100/20 = 5$ D.).

Or the simplest way is to measure the near point in inches as would be familiar with every one, and then transpose at once into D.'s. As, for instance, a near point of ten inches represents 4 D., a near point of eight inches, 5 D., and so on.

MEASURING ACCOMMODATION BY CONCAVE LENSES.

The strength of the accommodation can also be measured by means of a concave lens. Now it is a well-known fact to every optical student that a concave lens causes parallel rays of light to diverge as if they proceeded from a point near at hand; and the stronger the lens the more the divergence, because the rays have the same direction as if proceeding from the focus of the lens. In order, therefore, to preserve distinct vision through such concave lens, an eye must use the same accommodative power as it does when looking at an object situated at the focus of this concave lens.

As an illustration, a concave lens of 4 D. will give to parallel rays of light such a direction as if they diverged from a point situated ten inches back of the lens; and therefore an eye will have to bring into play the same amount of accommodative power in looking through such a lens as would be required in looking at an object situated at a distance of ten inches, the reason being that in each case the rays of light enter the eye of the observer under exactly the same degree of divergence. The action of the accommodation must increase the refracting power of the eye sufficiently to overcome or neutralize the effect of the concave lens precisely in the same degree as this concave lens tends to diminish the positive refracting power of this eye. For this reason an emmetrope who looks at distant objects through a concave lens experiences the same sense of fatigue in his eyes as when looking at an object close at hand.

Therefore the strongest concave lens through which an emmetropic eye is still able to see clearly at a distance is the measure of the amplitude of its accommodation. An emmetropic eye which is able to overcome an 11 D. concave lens in looking at a distance, possesses an amplitude of accommodation of 11 D. and its near point is situated at 9 centimeters in front of the eye ($100/11 = 9$), for the reason that this concave lens of 11 D. causes parallel rays to diverge as if they came from its focus, which is 9 centimeters behind it.

If an emmetropic eye is able to overcome a concave lens of 1/5 inch focus (8 D.) it will have an amplitude of accommodation equal in strength to a convex lens of the same focal distance, and its near point will be situated at five inches in front of the eye, since this particular concave lens causes parallel rays to diverge as if they proceeded from its focal point, which is five inches behind it

THE ACCOMMODATION IN HYPERMETROPIA.

The hypermetropic eye in a condition of repose is lacking in refractive power; in other words, presents a deficiency of refraction. In order for such an eye to be able to see at a distance, or in order to make such an eye emmetropic, either one of two conditions must be present: either a convex lens must be supplied equal in strength to the deficiency of refraction, or an equal effort of accommodation must be made.

A hypermetrope, therefore, who wishes to see at the same distance as an emmetrope, must accordingly employ a part more of his accommodation than the emmetrope (sufficiently more to neutralize or correct the deficiency of refraction). Consequently, in expressing the amount of accommodation used by a hypermetropic eye, the power necessary to adjust such an eye for infinity must evidently be added to that which changes its adjustment from infinity to the near point.

As a practical illustration, we will consider the amplitude of accommodation of a hypermetrope of 2 D., whose near point is situated at 20 centimeters. Such an individual must use 2 D. of accommodation to adjust his eyes for distance or to render them emmetropic. Now to adjust an emmetropic eye for a near point of 20 centimeters, there is required 5 D. of accommodation (100/20 = 5 D.). Therefore, in this particular case the amount of accommodation needed would be 5 D. + 2 D. = 7 D.

Or, perhaps, it can be made plainer to some readers by using the inch numbers, in which case we have a hypermetrope of 1/20, whose near point is situated at eight inches. He is required to use his accommodation to the extent of a + 1/20 lens for distance, and to the extent of a + ⅛ lens for the near point of eight inches, and his amount of accommodation used is 1/20 + ⅛ = 7/40, which means a convex lens a little stronger than + 1/6. Calculations such as these emphasize the difficulty of working with the vulgar fractions required by the inch system, and serve to point out one of the many advantages of the metric system.

NEAR POINT IN HYPERMETROPIA.

What is the near point of a hypermetrope of 3 D., who possesses an amplitude of accommodation of 6 D.? Inasmuch as this patient is required to use 3 D. of accommodation to see at a distance, there remain only 3 D. to adjust the eye for near vision. His near point, therefore would be 33 centimeters ($100/3 = 33$).

Using the inch system, the question would be, What is the near point of a hypermetrope of 1/12 inch who possessed an amplitude of accommodation of 1/6 inch? After using 1/12 to overcome his hypermetropia there would remain 1/12 for near vision ($1/6 - 1/12 = 1/12$), which would place his near point at twelve inches.

From these illustrations it can be seen that a hypermetrope of 3 D., or of 1/12, although respectively possessing an amplitude of accommodation of 6 D. and of 1/6 inch, is able to see no nearer than an emmetrope possessing an amplitude of only 3 D. or 1/12 inch. And reasoning from the same standpoint, if an emmetrope and a hypermetrope are able to see at the same near point, the hypermetrope must use the greater amount of accommodation. If a hypermetrope of 2 D. and an emmetrope both have their near points at 20 centimeters (eight inches), the former will need 2 D. more of accommodation. In order to see at that distance the emmetrope will require 5 D. of accommodation ($100/20 = 5$ D.), while the hypermetrope will need $5 + 2 = 7$ D. This shows the disadvantage under which a hypermetropic eye constantly labors and its need of a surplus of accommodative powers.

THE ACCOMMODATION IN MYOPIA.

In looking at the same near point, the myopic eye will require less accommodation than the emmetropic eye, because, when at rest, the latter is adjusted for distance, and the former for some definite point close at hand; and, therefore, at this point the myopic eye will see without any effort of accommodation, while the emmetropic eye will have to call into use part of its accommodation.

Therefore, in order to determine the amplitude of accommodation of a myopic eye, it will be necessary to subtract the refracting power by which the myope surpasses the emmetrope from that which would be required to adjust the emmetropic eye to the near point of the myope. In other words, the amplitude of accommodation which is normally present in an emmetropic eye will, in a myopic eye, be diminished by the amount of myopia present.

As an illustration, a case of myopia of 10 D. may be taken with a near point of 7 centimeters. Now, a near point of 7 centimeters in an emmetrope calls for an amplitude of accommodation of 14 D. ($100/7 = 14$ D.). In this case of myopia, 10 of the 14 D. of accommodation required are supplied by the error of refraction, and consequently, the amplitude of accommodation is the difference between the two, 14 D. — 10 D. = 4 D.

Or a case of myopia of one-tenth inch may be taken, with a near point of six inches. In emmetropia a near point of six inches represents an amplitude of accommodation equal to a convex lens of one-sixth inch, and, as part of this required convexity is supplied by the myopia, the amplitude of accommodation would be the difference between the two, $1/6 - 1/10 = 1/15$ inch.

"It's a poor rule that won't work both ways," and therefore the total amount of refractive power possessed by a myopic eye is the sum of its amplitude of accommodation and its myopia. For instance, a myope of 4 D. with an amplitude of accommodation of 6 D. possesses a positive refracting power of 10 D. ($6 + 4 = 10$ D.), which represents a near point of 10 centimeters ($100/10 = 10$), or four inches.

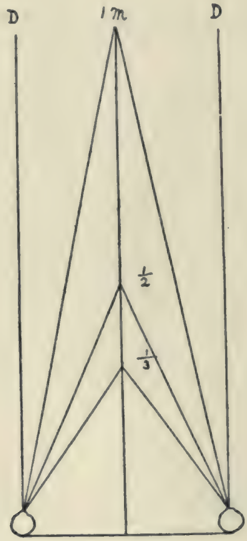
CONVERGENCE.

Having now completed his test of the accommodation, and having studied it not only as it exists in emmetropia, but also as it is affected by myopia and hypermetropia, the optometrist must remember that this is not the only factor or function which is called into play in binocular near vision, and his attention must be directed to the function of *convergence*, inasmuch as these two functions go hand in hand in the use of the eyes on any object nearer than infinity.

The function of accommodation is brought into action to adjust the refractive condition of the eye for vision at close distances, and the function of convergence is then called into play to alter the direction of the two eyes and place them in such a position that the image of the object looked at may fall on the yellow spot of each eye.

These two functions, accommodation and convergence, bear a constant relation to each other, within the limits of the amplitude of accommodation on the one hand and the amplitude of convergence on the other. As an object approaches the eyes, the accommodation and convergence are instinctively called into action; and the closer the object, the stronger must be the effort of both these functions. As vision is again turned to distant objects, the two functions relax in equal proportion.

For every increase of accommodation there is a corresponding increase of convergence, and the simultaneous actions of the



The meter angle.

muscle of accommodation and of the internal recti muscles are so intimately associated the one with the other that neither function can be satisfactorily used separately and independently. It would be an extremely difficult matter to converge without accommodating or to accommodate without converging.

THE METER ANGLE.

In the above illustration, when the two eyes are directed to distant objects (marked D), the visual lines will be parallel and there will be no angle of convergence.

When the eyes are directed to an object one meter away and the visual lines of the two eyes made to converge to this point, a certain angle of convergence will be formed by the meeting of the visual line of each eye with the median line, which is called The Meter Angle. It expresses the degree of convergence which is required to maintain binocular vision at that distance, and may be employed as the unit from which to express other degrees of convergence. In this case the metrical angle equals one, and is written as follows: C. = 1 (the C. being the sign for convergence).

If the object looked at be situated half a meter from the eye, the angle of convergence must, of necessity, be twice as large as when at one meter, and then we have C. = 2. If the object be brought closer, so as to be placed at a distance of one-third of a meter from the eye, the angle of convergence must be increased in the same proportion, and then we have C. = 3. If, on the other hand, the object of attention be situated at a greater distance than one meter, say at two meters or at four meters, the angle of convergence would be proportionately diminished and then we would have C. = ½, or C. = ¼. And just in proportion as the object is situated at a greater distance from the eyes will the angle of convergence diminish, until finally, when infinity has been reached, the angle of convergence will have disappeared and the visual lines become parallel.

AMPLITUDE OF CONVERGENCE.

When the eyes are directed to the closest point at which they are able to see distinctly, that is, the nearest point of binocular vision, the angle of convergence is at its greatest, and may be said to be adapted for its near point. When the eyes are directed to infinity, the angle of convergence is at its least; in fact, there is no longer any angle at all. The distance between these two points represents the *range of convergence*. The far point of convergence is always situated at infinity, or even beyond. The *amplitude of convergence* is the whole amount of convergence that can be exerted by the strongest effort of the internal recti muscles.

Now it is an established fact that the average normal emmetropic eye requires, for each point of distance of fixation of binocular vision, as many meter angles of convergence as it requires dioptres of accommodation; this refers to each and every point of fixation nearer than twenty feet. For a distance of one meter there is required an exercise of 1 D. of accommodation in emmetropia in order to focus the image on the retina; and at the same distance there will be required one meter angle of convergence in order that the internal recti muscles may so converge the eyes that their visual axes may cross at this point and thus form the image on the yellow spot of each eye. If the object be situated at a distance of half a meter, there will be required an exercise of 2 D. of accommodation, which corresponds to two meter angles of convergence. If at one-third a meter, we have 3 D. of accommodation and C. = 3.

The following table, taken from "Hartridge on Refraction," shows the angle of convergence in degrees for the different distances of an object when the eyes are 6.4 centimeters apart, which corresponds to a pupillary distance of about two and a half inches.

Distance of the object from the eyes.	The Metrical Angle.	Value expressed in degrees.
1 Meter	1	1° 50′
50 Cm.	2	3° 40′
33 "	3	5° 30′
25 "	4	7° 20′
20 "	5	9° 10′
16 "	6	11°
14 "	7	12° 50′
12 "	8	14° 40′
11 "	9	16° 30′
10 "	10	18° 20′
9 "	11	20° 10′
8 "	12	22°
7.5 "	13	23° 50′
7 "	14	25° 40′
6.5 "	15	27° 30′
6 "	16	29° 20′
5.5 "	18	33°
5 "	20	36° 40′

Although the functions of accommodation and convergence are so intimately connected and are exercised so completely in unison, yet this relation is not absolutely fixed and invariable, but it is possible for either function to be brought into use and exercised within certain limits independently of the other.

THE RELATION BETWEEN ACCOMMODATION AND CONVERGENCE.

The functions of accommodation and convergence, although so intimately connected, may within certain limits be used independently of each other. For instance, the accommodative effort may be increased or diminished, while the object is kept distinctly in view and the same degree of convergence maintained. This fact can be proven by the use of convex and concave lenses.

EFFECT OF SPHERES ON THE ACCOMMODATION.

When a concave lens is placed before the eye, the accommodation is at once called into action to neutralize or overcome the diminishing effect of the negative lens and to enable the object to be still distinctly seen. This increase of accommodation takes place without a corresponding increase of convergence.

When a convex lens is placed before the eye, the accommodation relaxes as much as possible, because the positive lens supplies all the refractive power needed without any effort of the accommodation, and if the lens is not too strong the object can still be clearly seen. This relaxation of accommodation takes place without a corresponding diminution of convergence.

EFFECT OF PRISMS ON THE CONVERGENCE.

And on the other hand, the convergence may be altered; it may be either increased or diminished, without any corresponding change in the accommodation. This fact can be proven by trial with a prism base in and a prism base out.

When a weak prism is placed before the eye with its base inward, it bends the rays of light toward its base, and in doing so it relieves the convergence to that extent; and, therefore, in order that double vision may not be produced, it becomes necessary for the eye before which the prism is placed to rotate outward. Now it has been ascertained that an individual is able to do this without destroying the distinctness with which the object is perceived. This proves that the angle of convergence has been lessened without a corresponding diminution of accommodation.

When a weak prism is placed before the eye with its base outward, the rays of light will again be bent toward its base, which in this case is outward. This calls for an extra effort of convergence in order to overcome the outward tendency of the prism and to maintain binocular vision, and therefore the eyeball must, of necessity, be rotated inward by the increased action of the internal recti muscles. It has been found possible for this to be done without interfering with the clearness of vision, which means without any change in the accommodation, a fact which goes to prove that the angle of convergence can be increased without a corresponding increase of accommodation.

POWER OF CONVERGENCE.

In early life the normal eyes possess a power of convergence of eighteen or twenty meter angles or more; but, of course, there are variations in this which are dependent somewhat on the condition of the refraction. For instance, a hypermetropic person, whose eyeballs are necessarily shorter and the internal recti muscles usually well developed, is able to exercise a greater amount of convergence in proportion than a person with emmetropic eyes; while, on the other hand, a myopic individual, whose eyeballs are longer and whose internal recti muscles are apt to be weak, is unable to exercise as great an amount of convergence as a pair of emmetropic eyes. For the convenience of optometrists tape measures have been prepared, which are marked on one side with centimeters (or inches) to show the distance at which an object is held and the point to which the eyes must converge, while the opposite side is marked with the corresponding meter angle.

RESERVE CONVERGENCE.

For the convenience and comfort of reading and near work, a certain amount of positive power of convergence is required, which should be double that required for the point or distance at which the reading or work is accustomed to be held. By way of illustration, if a patient reads or works at one-third of a meter from his eyes, that is, at a distance of thirteen inches, he will require three meter angles of convergence for that distance; or, in other words, C. = 3.

But if this was all the positive converging power possessed by this individual, he could not, for any length of time, or with any degree of comfort, keep his eyes converged to this point. No one is able to keep in use the full power of his convergence, any more than he is able to keep up the use of his full power of accommodation, and neither of these is possible. There must be a certain amount of power of convergence held in reserve, just as there must be a certain reserve amount of power of accommodation, and this should be twice as great as the power of convergence or accommodation employed.

In the above case, where three meter angles of convergence are required, the patient should possess at least three meter angles more of the power of convergence in reserve in order to work or read comfortably at thirteen inches.

DETECTION OF WEAK MUSCLES.

In the study of the function of convergence and its departure from the normal condition, it is necessary to know how to determine the strength of the internal recti muscles, as well as to detect any weakness of these or of the other ocular muscles.

The simplest method of testing any imperfection in the action of the ocular muscles is performed as follows: The head of the patient is to be held erect and he is asked to follow, with his eyes, the point of a pencil or any other small object as it passes from right to left and from above downward.

As the patient thus follows the pencil point, the observer must note not only whether each eye has a natural range of mobility, but also whether the two eyes move together in all directions. In attempting to do this the observer should remember that the movements of the eyes in a normal condition are something as follows:

Outward, 45 to 50 degrees.
Inward, 45 degrees.
Upward, 35 to 40 degrees.
Downward, 60 degrees.

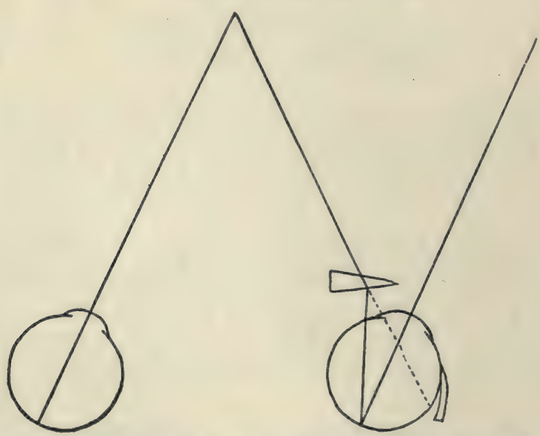
While there are various appliances for detecting and determining any limitation of the motion in one or both eyes in any certain direction, the observer is usually able to detect this by noticing whether or not the outer edge of the cornea reaches the canthus on the outer side (for example, when the eye is turned outward as much as its fellow), or whether the inner margin of the cornea of the other eye reaches the inner canthus; or, in other words, whether the movements of both eyes are exactly the same when regarded in connection with some definite fixed point.

SIMPLE TEST FOR CONVERGENCE.

It must also be noted in the same connection whether or not the two eyes converge equally. For this purpose it is usually sufficient to hold the point of a pencil a few feet in front of the patient exactly in the median line, and then gradually approach it nearer to the patient while he is asked to look at it intently. As he does this he must, of necessity, use his internal recti muscles and direct both eyes inward; and if this act of convergence is performed in a perfectly normal manner, there should be no difference in the movements of the two eyes. They should both converge to a certain point, the power of convergence varying somewhat with the age and muscular strength of the patient, and then, when the object is approached so close to the eyes that single vision is no longer possible, both eyes should turn outward at the same time, while usually the patient complains of a feeling of discomfort and fatigue. But if any insufficiency should exist, then when the object is held at a distance of three or four inches from the eyes in the median line for a short time, that internal rectus muscle which is weaker than normal is unable to perform its function and relaxes its efforts, and the eye turns outward.

THE TEST WITH PRISMS.

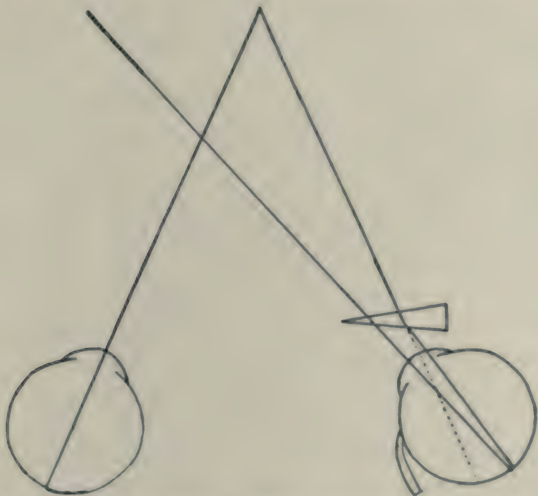
The next test consists in measuring the ability of the eyes to overcome prisms. When a person with good eyes looks at an object at a distance the eyes are at rest, no accommodation and no convergence is required, and the eyeballs are directed straight



Showing the action of a prism base in, which relieves convergence and taxes divergence and measures the strength of the external recti muscles.

ahead. If, now, a prism is held before one of the eyes, the rays of light passing through the prism will be bent toward the base of the prism, and the eye over which the prism is held will have to turn in the opposite direction in order to meet the entering ray, that it may be focused on the yellow spot of this eye and to correspond with the image formed in the other eye.

If the prism (say of five degrees) be placed before the right eye with its base in, for example, then the rays of light passing



Showing the action of a prism base out, which relieves divergence and taxes convergence and measures the strength of the internal recti musles.

through this prism will be bent inward, and it becomes necessary for the patient to rotate his eye slightly outward in order to meet the entering rays and bring them to a focus at the yellow spot, which act is accomplished by the action of the external rectus muscle of this eye.

If, on the other hand, the prism be placed before this eye with its base out, similar results are produced, only in this case it is the opposite muscle that is affected. Now the rays of light from an object are bent outward in passing through the prism, and it becomes necessary for the patient to rotate his eye slightly inward in order to preserve binocular vision, in which act he contracts the internal rectus muscle of this eye more than usual.

These two conditions are well illustrated in the drawings, a careful study of which will be of much assistance to the optometrist in understanding the action of prisms and our means of measuring the convergence and divergence of the eyes.

METHOD OF MEASURING DIVERGENCE.

This may be considered as a negative quantity (negative convergence) or as the minimum of convergence of the visual axes, which is really identical with their maximum of divergence. It also may be said to express the strength of the external recti muscles.

The measure of the negative convergence or of the positive divergence is determined by finding the strongest pair of prisms with their bases inward, which are compatible with single vision of a distant object. The deviating angle of each prism expresses the "absolute minimum of convergence" for each eye.

The drawing illustrates how a prism with its base in causes the eye to rotate outward, thus making it an effort of the external rectus muscle. If, now, the prism which is held before the eye be a very strong one, so strong that it is impossible for the external rectus muscle to draw the eye out far enough to meet the entering ray, then this ray will not fall upon the yellow spot, but will strike the retina on the inside of it, and thus double vision will be produced, one image in its natural position, while the image of the right eye, being projected outward from its wrong position, will be seen very much to the right.

We have now described the action of a weak prism and of a strong prism. In the first case the eye rotates outward and binocular vision is preserved; in the second case the prism is so strong that the external rectus muscle is not powerful enough to prevent diplopia. Between these two extremes and after a careful trial, a prism can be found (perhaps 6° to 8°) which is the strongest that will not produce double vision; the number of this prism will express the strength of the external recti muscles and the ability of divergence.

In measuring the divergent power of the external recti muscles, it is important that the point of fixation during the experiment should be at some considerable distance, if it is desired to ascertain the *absolute* minimum of convergence. The reason for this is that the knowledge on the patient's part that the object is at a distance, removes from his mind any suggestion of the need of convergence, and to that extent assists the action of the external recti muscles, or allows them unhindered to exert their full divergent power. And an additional reason is found in the close relation existing between accommodation and convergence, and the remoteness of the object relieving the convergence in the same proportion as the accommodation.

DECENTERING OF LENSES.

If the patient under examination wears glasses for any existing optical defect, and if the glasses are not too weak, the experiment may be made of decentering them to gain their prismatic effect, and measuring the strength of the external recti muscles in this way. The base of the prism must be in, and, therefore, if the patient was myopic and wore concave lenses, they would have to be separated in order to secure the base of the prism in the proper direction. While if the patient was hypermetropic and wore convex lenses of sufficient strength, they would have to be approximated or decentered in for the same reason.

As the patient looks through his glasses, the convex lenses are approximated or the concave lenses are separated, until double vision results. Now the optometrist has the strength of the glass and the distance it is decentered, from which he can find the degree of prism involved. An elaborate table has been prepared, showing the prismatic effect of decentered lenses, in which for every strength of lens from .50 D. to 20 D., and for every millimeter of decentering from 1 millimeter to 32 millimeters, there is a corresponding and fixed equivalent in prismatic effect.

As an example, a patient may be taken who is wearing — 4 D. glasses, and these glasses may be separated until the distance between the optical centers of the lenses is 10 millimeters more than the distance between the centers of the pupils of the two eyes. In this case each lens is displaced 5 millimeters, and a reference to the table shows that a lens of 4 D. with a decentering of 5 millimeters possesses a prismatic equivalent of 1° 10′.

It has been found that with vision at twenty feet or more, that is, when accommodation and convergence are normally at rest, the average power of the external recti (or abducting) muscles is measured by a prism of about 8°, sometimes a little less (6°) and sometimes a little more (9°). This refers to emmetropia; or, if any optical defect is present, it must first be corrected by the proper lenses before the test is made.

METHOD OF MEASURING CONVERGENCE.

This has reference to positive convergence or the absolute maximum of convergence, and it may also be said to express the strength of the internal recti muscles, and it is determined by finding the strongest prism over one eye or the strongest pair of prisms over both eyes with their bases outward, which will not destroy single vision of a test-type or printed page held as close to the eyes as accommodation will permit. The optometrist should note that in this case the test is made with the object looked at as close as possible, in order that the accommodation required to focus an object so close at hand will assist the convergence to reach its maximum.

Another test, and an old established one it is, is for the optometrist to approach his finger toward the root of the patient's nose, who keeps his eyes fixed upon the finger until it is so close that the maximum of convergence is reached, and then one eye will deviate outward. This test, however, scarcely discovers the *absolute* maximum of convergence, because as the object approaches the eyes diffusion circles begin to appear on the retina and increase in size as the object gets nearer, until the ciliary muscle gives up the impossible task of accommodation, which then relaxes, and with it the convergence. The same thing occurs in absolute hypermetropia, where the efforts of accommodation cease as soon as the patient finds he is unable to exercise his accommodation to a sufficient degree to afford clear and distinct vision.

In reference to the test first mentioned as the one on which to rely to measure the strength of convergence, some authorities call attention to the chromatic dispersion produced by the prisms as spoiling the clearness of the pictures produced on the retina, and therefore vitiating to some extent the value of the test. This can be avoided only by the use of monochromatic light, which is scarcely available by the optometrist in his every-day work.

RANGE OF CONVERGENCE.

When the results of the tests for divergence and convergence, that is, the minimum of convergence and the maximum of convergence, are added together, the *absolute* range or amplitude of convergence is obtained, of which perhaps not more than one-third or one-fourth can be used continuously for comfortable vision in the ordinary occupations of life.

The *relative* range of convergence is determined by the strongest pair of prisms bases in and by the strongest pair of prisms bases out, which will not produce double vision of an object at some fixed distance. The distance most suitable would be that at which the patient's daily work is done (occupation distance), and for which spectacles are most required.

The prisms bases in measure the negative part of the range, and the prisms bases out its positive part. This is a very valuable test, but its value largely depends on the ratio that should exist between the negative and the positive parts, and then noting the departure from this normal ratio. This must be well worked out for different distances of vision; but, unfortunately, there is no such complete table to which the optometrist can refer.

However, there are some data on the subject at hand which can be made use of. For instance, at twelve inches the negative and positive parts of the range of convergence are equal, while at shorter distances the positive part begins to exceed the negative.

It is a fact that the normal relation existing between convergence and accommodation becomes altered temporarily by prolonged efforts to overcome strong prisms, and, therefore, all these tests should be made as quickly as possible.

In testing the ranges of convergence with a single prism, it must be divided in half in order to get the result for each eye. Or, if a pair of prisms of unequal numbers are used, that is, one of the prisms weaker than the other, the sum of the two must be divided in half in order to get the result for each eye. But, unquestionably, the best way is to use a pair of similar prisms, of the same degree before each eye.

It should not be understood that there is any prism which measures definitely the normal strength of either pair of recti muscles. There are, indeed, in apparently normal eyes, remarkable variations in the ability to overcome prisms placed in the position required by the tests. A considerable number of observations seem to show that an emmetrope possesses a power of convergence of about 30°, and of divergence of 8°, the average ratio between the two being 100 to 28.

A hypermetrope requires a greater amount of accommodation to overcome his defect, and, therefore, it might be expected that his power of convergence would also be proportionately greater than with an emmetrope; but, on the contrary, it is usually less. In these cases the power of convergence is about 25°, and of divergence 12°, the average ratio between the two being as 100 to 48.

NOMENCLATURE OF MUSCULAR ANOMALIES.

Of late years a new nomenclature has been proposed and adopted for expressing degrees of muscular weakness, and as it is being used to a considerable extent by writers of books, and as the optometrist is apt to meet it in his reading, it is important for him to familiarize himself with it.

Orthophoria is the term used to denote parallelism of the visual lines or normal power of the muscles; a condition of the eyes where there is perfect balance and co-ordination of all the extrinsic ocular muscles.

Heterophoria is the term employed to denote some departure from the normal parallelism of the visual lines, and signifies that condition of the eyes where there is a want of balance of the extrinsic ocular muscles due to insufficiency or paralysis of some one of these muscles.

Esophoria, a convergence or tendency of the visual lines inward; or, insufficiency of the external recti muscles.

Exophoria, a divergence or tendency of the visual lines outward; or, insufficiency of the internal recti muscles.

Hyperphoria (right or left) is the term used to denote a tendency of the right or left visual line to place itself in a direction above that of the opposite side; or, insufficiency of the inferior rectus muscle.

Cataphoria (right or left) is the term used to denote that the visual line of one eye is below that of its fellow; or, insufficiency of the superior rectus muscle.

COMPOUND TERMS.

Tendencies of the eye to deviate in an oblique direction are expressed by the following terms:

Hyper-esophoria signifies a tending of the visual line upward and inward; or, insufficiency of the inferior and external recti muscles.

Hyper-exophoria signifies a tending of the visual line upward and outward; or, insufficiency of the inferior and internal recti muscles.

Eso-cataphoria signifies a tending of the visual line inward and downward; or, insufficiency of the external and superior recti muscles.

Exo-cataphoria signifies a tending of the visual line outward and downward; or, insufficiency of the internal and superior recti muscles.

In these four latter forms of deviation, the oblique muscles are also frequently at fault.

TESTS FOR MUSCULAR INSUFFICIENCY.

In testing the balance of the muscles in order to detect any insufficiency thereof, the first step is to dissociate convergence and accommodation, or to produce vertical diplopia. This is accomplished by a vertical prism (base either up or down), which removes the stimulus for singleness of vision, and if any muscular insufficiency is present, it will be made manifest by the overaction of its opposing muscle. A very weak prism will suffice for this purpose, because the inferior and superior recti muscles are able to overcome only a very small amount—not more than two or three degrees; hence, a prism a little stronger than this is recommended, and any prism from five to fifteen degrees may be used.

PRISM TESTS.

The vertical prism is placed before one eye and the patient is directed, with both eyes open, to look at a distant object, say a candle flame at a distance of twenty feet or more. Vertical diplopia being produced by the prism, two images of the candle flame will be seen, one above the other. If the upper image is exactly above the lower, both being in the same vertical line without any muscular effort, the inference is that there is no insufficiency of either the internal or external recti muscles; or, in other words, these muscles balance each other.

But if the two vertical images are not in the same straight line, muscular insufficiency is known to exist, and the relative positions of the two images will indicate the particular form of insufficiency, whether it be of the internal or the external recti muscles.

If the prism be placed over the right eye with its base up, the image belonging to this eye will be the lower one. If, now, the lower image deviates to the right, the condition known as homonymous diplopia is present, which means that the right image is seen by the right eye and the left image by the left eye. This condition is due to an insufficiency of the external recti muscles (a condition of *esophoria*), and the degree of prism with its base out that is necessary to bring and retain the two images on the same vertical line the optometrist can accept as the measure of the amount of the insufficiency.

If, on the other hand, the lower image deviates to the left, the condition present would be known as crossed diplopia, in which the right image belongs to the left eye and the left image to the right eye. This crossing of the images is due to an insufficiency of the internal recti muscles which, according to the nomenclature as given above, would be *exophoria*. The degree of prism with its base in that is necessary to bring and retain the two images on the same vertical line will indicate the amount of insufficiency.

DOT AND LINE TEST.

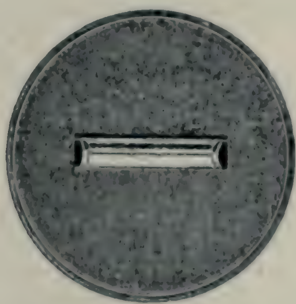
The test should then be repeated for near objects by means of the *dot and line*, in order to detect any departure from the normal equilibrium of the internal or external muscles.

Every optometrist is more or less familiar with this figure and its method of use. A prism is placed over one eye with its base vertical. The patient is asked to look at the above figure, which is drawn on a card, and held in the hand at a distance of twelve or fifteen inches. If the patient says he sees two dots on one line, the muscles are assumed to be normal. If he sees two dots and two lines laterally displaced, there is insufficiency; and the direction of the displacement will indicate whether it is the internal or the external recti muscles that are at fault.

If the lower image is on the same side as the eye over which the prism is placed (homonymous diplopia), the insufficiency is in the external recti and is corrected by a prism base out. If the lower image is on the opposite side from the eye over which the prism is placed (crossed diplopia), the insufficiency is in the internal recti muscles, and is to be corrected by a prism base in.

MADDOX TESTS.

Maddox, an English oculist, has given the optical world several very valuable tests for the detection of muscular insufficiencies. *The Maddox Rod* consists of a glass rod or cylinder (usually



The Maddox rod.

of colored glass and preferably red) set in a stenopaic opening of a metal disk. *The Maddox Groove* is a mounted lens of red glass, translucent, but not transparent, with a transparent groove ground across its equator.

These lenses (both the rod and the groove) act as strong cylinders, and elongate the candle-flame or gas-light looked at into a long, narrow streak of light, running at right angles to the direction in which the cylinder is placed before the eye.

This apparent lengthening of a flame into a line of light, when looked at through such a strong cylindrical lens by one eye, causes such a dissimilarity between the two retinal images as to destroy all desire to unite them and preserve binocular vision, and this fact is utilized as the basis on which the Maddox tests are founded. One of the advantages of this principle is that ex-

The Maddox groove.

tremely great care is not required to see that the cylinder is exactly vertical or exactly horizontal, because slight malpositions of the cylinder do not materially vitiate the result, as is the case when testing with prisms.

HOW TO USE THE MADDOX ROD.

In making the test, the Maddox rod or groove is placed over one eye in the trial-frame, while the other eye is either left uncovered, or a light blue glass may be used before this eye in order to more nearly equalize the illumination of the two images. The rod or groove is placed in the trial-frame in either a horizontal or a vertical position, which, it should be remembered, will cause the flame of light to be elongated into a streak of light and appear in either the vertical or horizontal meridian; while the image formed in the other eye will be that of the unaltered flame, except as its intensity of illumination may be modified by the colored lens.

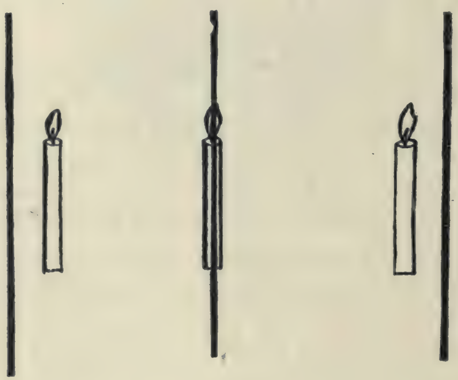
On account of the great difference in size, shape and appearance of the two images as formed on the retina of each eye, binocular vision is destroyed, and, consequently, there is no tendency or effort to fuse the two images, and this allows each eye to take its natural position of rest; or, in other words, gives the eyes over to the natural control each of its own muscles, uninfluenced by the desire that exists in every man's mind to preserve binocular vision. This desire for binocular vision is naturally so strong that great muscular insufficiencies are oftentimes overcome and masked by the effort to maintain it. The removal of this desire, or the placing of the eyes each under the free control of its own muscles, will reveal any existing insufficiency of any of them. If, on the removal of this natural stimulus for binocular vision, the eyes still remain straight, and both eyes equally directed to the object, it is safe to assume that there is no insufficiency of any of the ocular muscles; if, on the other hand, there is a deviation of one or both eyes, or a separation of the two images as formed in each eye, it is proof of the existence of insufficiency of one or more of the ocular muscles.

The best flame is that of a gas jet turned low at a distance of fifteen or twenty feet, or an electric light with a frosted globe and covered by an asbestos chimney with a small aperture, which the patient is directed to look at with both eyes open through the trial-frame, which had been fitted with the rod and the colored glass, as above described. If *orthophoria* exists, that is, if there is a perfect balance and co-ordination of all the ocular muscles, the streak of light seen by the eye over which the rod is placed will pass directly through the flame as seen by the other eye, and they will both occupy the same position. If, however, the streak of light is to one side or the other of the flame, *heterophoria* is known to exist, that is, a departure from the normal parallelism of the visual lines.

If any marked error of refraction is present in the eye that is being examined, it should be corrected by the proper lens, after which the glass rod should be placed over the right eye, if it is desired to examine the muscles of this eye first. The flame is then seen in its natural condition by the left eye and is fixed by that eye, while the streak of light seen by the other eye will be influenced and thrown to one side or the other, according to the strength or weakness of the internal or external recti muscles of this eye. The glass rod is placed before the eye in the horizontal meridian when it is desired to examine the internal and external recti muscles (or the adductors and abductors, as they are sometimes called), for the reason that with the rod in this position the line of light is vertical, and a lateral deviation of a vertical line could more quickly be noticed than could a perpendicular deviation; or, in other words, the line should be at right angles to the deviation which it is desired to measure.

EXOPHORIA OR ESOPHORIA.

The flame of light being fixed by the left eye, any muscular insufficiency of the right eye will be made manifest by the line of light placing itself to one side or other of the flame. If the line appears on the right side, that is, on the same side as the eye that is being examined, it shows the existence of *esophoria,* or an insufficiency of the external recti muscles. The degree of esophoria is measured by the strength of prism, base out, that is required to



bring the line of light directly over the flame. This form of diplopia is known as homonymous.

If the line of light appears on the left side, that is, on the opposite side from the eye that is being examined, it shows the existence of *exophoria,* or an insufficiency of the internal recti muscles. The degree of exophoria is measured by the strength of prism, base in, that is required to bring the line of light directly over the candle flame. This form of diplopia is known as heteronymous, or crossed, and is the most common form.

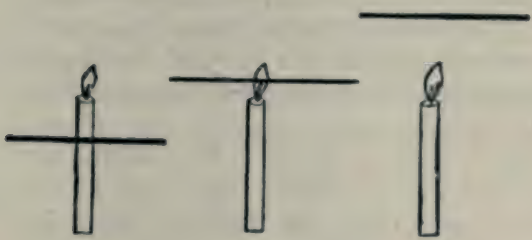
The glass rod can then be placed over the left eye and the tests repeated in the same way, and it will be found if there had been esophoria of the right eye, there will also be esophoria of the left, that is, if the insufficiency of the muscles of the right eye had been seated in the external rectus, it will be found in the same muscle of the left eye. Likewise, if there had been exophoria of the right eye, there will also be exophoria of the left, that is, if the internal rectus muscle of the right eye is weak, the internal rectus of the left eye will be affected in the same form and degree.

In the first case the correction is made by a prism, base out, the whole amount of which can be placed over one eye, or the prism can be divided and half placed over each eye. In the second case the correction is made by a prism, base in, which can be placed over either eye, indifferently, or divided between the two eyes.

DETECTION OF HYPERPHORIA.

In the examination of the superior and inferior recti muscles of the eyes, the glass rod is placed in the trial-frame in a vertical position. This causes the line of light to be seen horizontally, and the easier permits a perpendicular deviation to be detected, for the reasons given above.

The rod is first placed over the right eye and a light-colored glass over the left eye, both lenses being in the trial-frame, and again the patient is directed to look with both eyes at the gas jet fifteen or twenty feet away. The flame is seen in its normal shape



and is fixed by the left eye, while the image formed in the right eye is a horizontal line of light, which will either pass through or over the flame, or be placed above or below it, according as these muscles are normal or abnormal in strength.

If the line of light is identical with the flame, the superior and inferior recti muscles are assumed to be normal, which condition is expressed by the term *orthophoria*. If the streak of light is seen below the flame, this proves an insufficiency of the inferior rectus muscle of this eye; this condition is known as *hyperphoria*, which means a tendency of this eye to place its visual line in a direction above that of its fellow, which, when projected outward, causes the image to be seen below. The degree of the hyperphoria is measured by the strength of the prism, base down, which is required to place the line of light directly over the flame.

If the line of light is seen above the flame, there is an insufficiency of the superior rectus muscle of this eye, which condition is known as *cataphoria,* which is a term used to denote that the visual line of this eye is below that of the other, the projection of which outward causes the image to be seen above. The degree of the cataphoria is measured by the strength of the prism, base up, which is required to place the line of light directly over the flame.

Instead of the term cataphoria we may confine ourselves to the word hyperphoria, designating it right or left hyperphoria, respectively, when the right or left image is the lowest.

COMPOUND MUSCULAR DEFECTS.

In addition to the tests just given for measuring the strength of the internal and external recti muscles, and of the inferior and superior recti muscles, Maddox has introduced another test to discover any compound muscular error, as by its use can be ascertained at once any defect of the vertical muscles with that of the horizontal muscles, as well as of the oblique muscles.

This is accomplished by his double prism test, which consists of two prisms set together in a rim with their bases together, and which has the effect of making objects appear double.

In the practical application of this test, the metal rim enclosing the double prism is placed in the trial-frame over one eye, while the other eye is excluded from vision by the opaque disk. Care must be taken to see that the line of separation between the two prisms shall be directly in front of the center of the pupil, which will have the effect of forming two images in this eye and making any object looked at appear double. If preferred, the trial-rim may be held in the hand before the eye. In each case the dividing line between the prisms is to be placed horizontally.

The patient is asked to look at any conspicuous object, as a door-knob or a candle-flame, at a distance of fifteen or twenty feet. The double prism may be placed over the right eye and the metal disk over the left eye, in which case the picture formed in the right eye will be two images of the object separated vertically quite a little distance (see Fig. 1, page 323).

If, now, the left eye be uncovered by the removal of the opaque disk, a third image of the object will be seen, as the picture formed in this eye is a single image of the object uninfluenced by any disk or lens; and if orthophoria exists, this third image (belonging to the left eye) will be midway between the

Maddox's double prism.

two images of the right eye and in the same vertical line, as represented in Fig. 2. This, then, is the test for detecting any insufficiency of the internal or external recti muscles, and the fact that the three images are seen on the same straight vertical line indicates that these muscles are normal.

The middle image must be not only on the same vertical line in orthophoria, but must also be equidistant from the upper

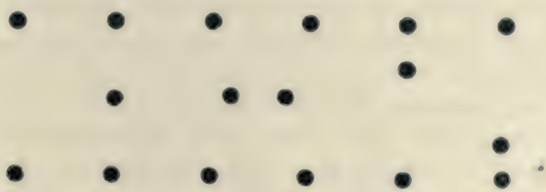


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5 FIG. 6

and lower images. If the middle image deviates from this exact central position, and approaches either the upper or lower image, it indicates the existence of some insufficiency either of the superior or inferior recti muscles.

As just mentioned, the deviation of the middle object from the straight vertical line indicates an insufficiency either of the internal or external recti muscles, and the direction of the deviation will determine which of the muscles is affected. If the middle image is seen to the right (as in Fig. 3), it indicates exophoria, or an insufficiency of the internal rectus muscle. A little thought will show the student that this is a condition of heteronymous, or crossed, diplopia, the right image of the middle dot belonging to the left eye, and the left image of the upper and lower dots belonging to the right eye. This condition is corrected by a prism, base in, and the measure of the insufficiency will be that degree of prism, base in, over the left eye which throws the middle image in on the same vertical line as the other two.

If the middle image appears to the left (as in Fig. 4), it indicates esophoria, or an insufficiency of the external rectus muscle. This corresponds to a condition of homonymous diplopia, in which the right image of the upper and lower dots is seen by the right eye, and the left image of the single middle dot is seen by the left eye. This condition is corrected by a prism, base out, and the measure of the insufficiency of the external rectus muscle will be that degree of prism, base out, over the left eye which throws the middle object out on the same vertical line with the upper and lower images.

HYPERPHORIA BY THE DOUBLE PRISM.

If the middle image appears to move up and approaches the upper image (as in Fig. 5), it indicates cataphoria of the left eye, or, an insufficiency of the superior rectus muscle of this eye. In this condition the antagonistic muscle, the inferior rectus, being the stronger, draws the eye down and places its visual line in a direction below that of its fellow, in which position the projection of the image outward throws it up, because the image is formed on the retina below the yellow spot, on account of the fundus being moved upward by the downward direction of the front of the eye. This condition is corrected by a prism, base up, and the measure of the insufficiency of the superior rectus muscle will be that degree of prism with its base up over the left eye which throws the image down to its proper position, midway between the upper and lower ones.

If the middle image appears to move down and approaches the lower (as in Fig. 6), it indicates hyperphoria of the left eye, or, an insufficiency of the inferior rectus muscle of this eye. In this condition the antagonistic muscle, the superior rectus, being the stronger, draws the eye up and places its visual line in a direction above that of its fellow. When the eye is thus turned up the fundus of the eye is thrown down, and, consequently, the image is formed on the retina above the yellow spot, and, when projected outward, is seen below its normal position. This condition is corrected by a prism, base down, and the measure of the insufficiency of the inferior rectus muscle will be that degree of prism with its base down over the left eye which will cause the image to move upward and assume its proper position, midway between the upper and lower images.

HOW THE CORRECTING PRISM IS PLACED.

In these measurements the correcting prism is always placed over the left eye, because it is the image of this eye that deviates. The conditions may be reversed and the double prism placed over the left eye, in which case it will be the image of the right eye that deviates, and then the correcting prism will be placed over the right eye. It should be noted that the base of the correcting prism is always placed over the insufficient muscle; or, in other words, the apex of the prism is in the same direction in which it is desired to move the middle object.

These tests, with their resulting deviations, will bear close study. No man can carelessly read them over and gather their full meaning, but the optometrist who desires to understand this somewhat intricate subject of muscular troubles must re-read these tests and study them closely, and he will see that there is a fixed principle that governs and explains them all; and when this is understood and becomes clear to the mind, the whole subject, that formerly seemed difficult and mixed, will open up clearly and beautifully.

COMPOUND INSUFFICIENCY.

If the middle image is seen to the left and above (as shown in Fig. 7, page 326), it indicates a condition of eso-cataphoria, which means an insufficiency of both the external and superior recti muscles of the left eye. In this condition the antagonistic muscles, the internal and inferior recti, being the stronger, draw the eyeball downward and inward, and place its visual line in a direction below and to the inside of its fellow. When the eye is thus turned downward and inward, the fundus of the eye is placed upward and outward, and, consequently, the image is formed on the retina below the yellow spot and to the inside of it, and, when projected outward, is seen above and to the left of its normal position.

If the middle image is seen to the right and above (as shown in Fig. 8), it indicates a condition of exo-cataphoria, or, an insufficiency of both the internal and superior recti muscles of the left eye. Under these circumstances, the antagonistic muscles, the external and inferior recti, being the stronger, draw the eyeball

FIG. 7 FIG. 8 FIG. 9 FIG. 10

outward and downward, and place its visual line in a direction below and to the outside of its fellow. In this position the fundus of the eye is turned upward and inward, and, consequently, the image is formed on the retina below the yellow spot and to the outside of it, and, when projected from the eye, is seen above and to the right of its normal position.

If the middle image appears to the left and below (as shown in Fig. 9), it indicates a condition of hyper-esophoria, or, an insufficiency of both the external and inferior recti muscles of the left eye; in which case the antagonistic muscles, the internal and superior recti, being the stronger, draw the eyeball inward and upward, and place its visual line in a direction above and to the inside of its companion. In this position, with the fundus of the eye turned downward and outward, the image is formed on the retina above and to the inside of the yellow spot, and, when projected out from the eye, appears below and to the left of its normal position.

If the middle image appears below and to the right (as shown in Fig. 10), it indicates a condition of hyper-exophoria, or, an insufficiency of both the internal and inferior recti muscles, in which case the antagonistic muscles, the external and superior recti, draw the ball outward and upward, and place its visual line in a direction above and to the outside of the other eye. In this position, the fundus of the eye being turned downward and inward, the image is formed on the retina above the yellow spot and to the outside of it, and, when projected out from the eye, appears below and to the inside of its normal position.

DETECTION OF INSUFFICIENCY OF THE OBLIQUE MUSCLES.

In the detection of insufficiencies of the oblique muscles, Maddox double prism is again brought into use, and is placed over

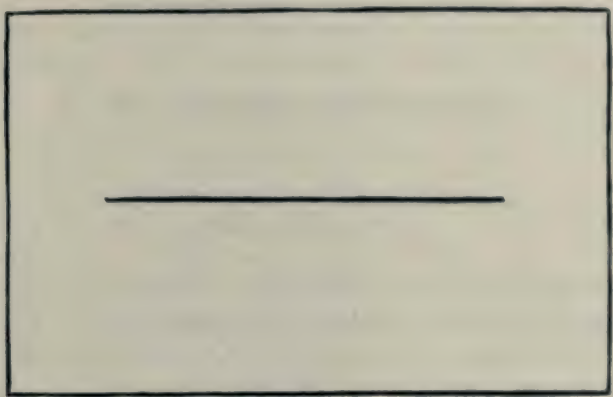


FIG. 11

one eye, as in the preceding tests, while the other eye is covered by the opaque disk. The patient is asked to look at a card, which is held in his hand at a distance of eighteen inches, and which con-

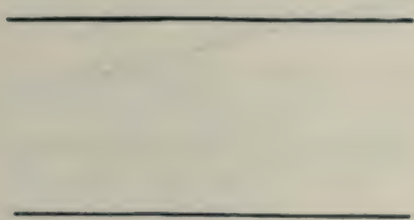


FIG. 12

tains nothing but a plain horizontal line (as in Fig. 11). He will at once see two lines parallel with each other (as in Fig. 12), because the effect of the double prism is to produce double vision, or vertical diplopia, if the prism is placed before the eye in such a way that its prisms are vertical and the line of separation horizontal and directly in front of the center of the pupil.

The other eye is now uncovered by the removal of the opaque disk, when a third line is seen between the other two; if the muscles are normal, this third line should be equidistant between the two and parallel with them (as in Fig. 13). If there is any insufficiency or want of harmony on the part of the oblique muscles, this test will at once detect it by a departure of the middle line from its parallelism with the other two lines, the one end of the middle line pointing up and the other down, or *vice versa*, according to the nature of the particular case.

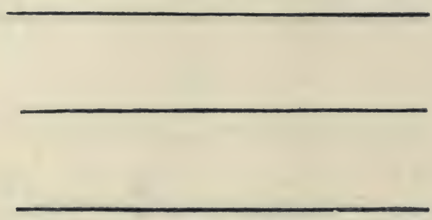


FIG. 13

When it is desired to test the muscles of the right eye, which is usually done first, the double prism is placed over the left eye, and the patient's attention is directed to the middle line. This middle line is seen by and belongs to the right eye, and will depart from its normal position if there is any insufficiency of the oblique muscles, while the upper and lower lines, which are seen by and belong to the other eye, which is not under examination, always remain stationary.

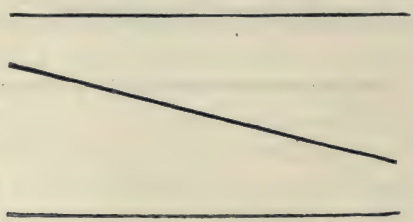


FIG. 14

We will suppose that the patient says the right end of middle line slants toward the bottom line, and that the middle and lower lines seem to converge at the right and diverge at the left (as in Fig. 14); what is the optometrist to understand from this? Does this deviation tell him, in unmistakable language, which muscle is affected, and whether it is too weak or too strong? or what significance does it convey to his mind?

ACTION OF THE OBLIQUE MUSCLES.

In the study of these deviations, the optometrist should refresh his memory as to the origin and insertion and function of the oblique muscles. The *superior oblique* muscle is placed at the upper and inner side of the orbit. It has its origin at the apex of the orbit, and as it passes forward to the inner angle of the orbit it terminates in a rounded tendon, which plays in a ring or pulley, formed by fibro-cartilaginous tissue attached to a depression on the frontal bone. This tendon passes outward and backward beneath the superior rectus muscle to the outer part of the globe of the eye, and is inserted in sclerotic coat midway between the cornea and the entrance of the optic nerve, and between the superior and the external recti muscles.

The *inferior oblique* muscle is a thin, narrow muscle, and placed near the anterior margin of the orbit. It takes its origin from the anterior and inferior portion of the orbit, and passes outward and backward beneath the inferior rectus muscle and between the eyeball and the external rectus, and is inserted into the outer part of the sclerotic coat between the superior and external recti muscles, and near the tendon of insertion of the superior oblique.

The oblique muscles rotate the eyeball on its antero-posterior axis, this kind of movement being required for the correct viewing of an object when the head is moved laterally, as from shoulder to shoulder, in order that the picture may fall in all respects on corresponding parts of the retina of each eye. The superior oblique muscle rotates the eyeball slightly downward and outward; while the inferior oblique muscle rotates the ball slightly upward and outward. Or, in other words, the action of the superior oblique muscle is to rotate the eyeball on its axis in such a way as to turn the superior portion inward and the inferior portion outward; while the action of the inferior oblique muscle is to rotate the superior portion of the eyeball outward and the inferior portion inward.

OBLIQUE INSUFFICIENCIES.

Therefore, when the optometrist tests the right eye and finds the middle line slanting in such a way as is shown in Fig. 14, he knows there is weakness or insufficiency of the inferior oblique muscle of this eye, which allows the eye to be rotated in this direction.

If, however, the patient says the right end of the middle line slants toward the top line, and that the middle and upper lines seem to converge at the right and diverge at the left, as Fig. 15), the optometrist is able by the same line of reasoning to conclude that in this case there is a weakness of the superior oblique muscle of the right eye.

After having tested the oblique muscles of the right eye in this way, the examiner removes the Maddox double prism from the

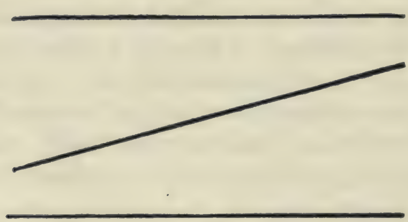


FIG. 15

left eye and places it over the right eye, and then he is in a position to examine the oblique muscles of the left eye, as the image of the middle line now belongs to this eye. If now the patient says he sees the right end of the middle line slanting toward the bottom line, and that the middle and lower lines seem to converge at the right and diverge at the left (as in Fig. 14), the optometrist knows that the superior oblique muscle of this left eye is below the normal strength.

If, on the other hand, the patient says the right end of the middle line slants toward the top line, and that the middle line and top line seem to converge at the right and diverge at the left (as in Fig. 15), the optometrist recognizes this as a case of insufficiency of the inferior oblique muscle of this left eye.

A careful study of these tests and digrams will show that the inferior oblique muscle of the right eye acts in conjunction with the superior oblique of the left eye; as the upper portion of the right eye rotates outward by the action of its inferior oblique muscle, the upper portion of the left eye follows it by rotating inward by the action of its superior oblique muscle. And, therefore, an insufficiency of the inferior oblique muscle of the right eye will be detected by the same test and result as an insufficiency of the superior oblique muscle of the left eye (as in Fig. 14).

On the other hand, the superior oblique muscle of the right eye acts in conjunction with the inferior oblique muscle of the left eye; as the upper portion of the right eye rotates on its axis inward by the action of the superior oblique muscle, the upper portion of the left eye follows it by rotating outward on its axis by the action of its inferior oblique muscle. And, therefore, a weakness of the superior oblique muscle of the right eye can be detected by the same test and result as an insufficiency of the inferior oblique muscle of the left eye (as in Fig. 15).

CHROMATIC TEST.

This is a corroborative test for the errors of refraction, and depends upon chromatic aberration, or the difference in refraction of different colored rays of light. If the reader will refer to the subject of chromatic aberration on page 134, and the diagram of the separation of colors on page 135, he will see the explanation of the principle on which this test is based. It should be constantly borne in mind that the red rays are the least deviated from their original course, and the blue and violet rays the most. The chromatic lens used in this test is made of cobalt blue; it suppresses all the colors except the two extremes, allowing only the red and blue rays to pass. The flame of a lamp or candle is used at a distance of fifteen or twenty feet, and is viewed through the chromatic lens, when the blue rays, being the most strongly

refracted, will come to an earlier focus and the red rays, being the least refracted, will meet at a later focus.

EMMETROPIA OR AMETROPIA BY THE COLOR TEST.

If the eye is *emmetropic,* the focus of the blue rays will be as far in front of the retina as the focus of the red rays is behind it, and, consequently, the two sets of rays will intersect at the position of the retina, and this intermingling of the two colors at this point will cause the flame to appear as of a diffuse violet color with a border of a slightly deeper hue.

If the eye is *hypermetropic,* the retina will be advanced and will approach the focus of the blue rays (as is shown in the diagram), and this will cause the flame to appear with a blue center and a red border.

In a *myopic eye,* on the other hand, the position of the retina is farther back, in proximity to the focus of the red rays (as illustrated in the diagram), and in this case the flame will appear with a red center and a blue border.

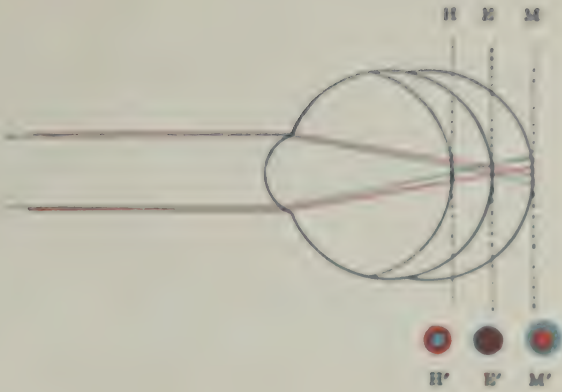
To determine the degree of defect we find that convex or concave lens that will correct the chromatic aberration. In hypermetropia we prescribe the convex lens that will dispel the red border and convert the light into a violet red. In myopia we find the concave lens that will diffuse the red center and blue border into one.

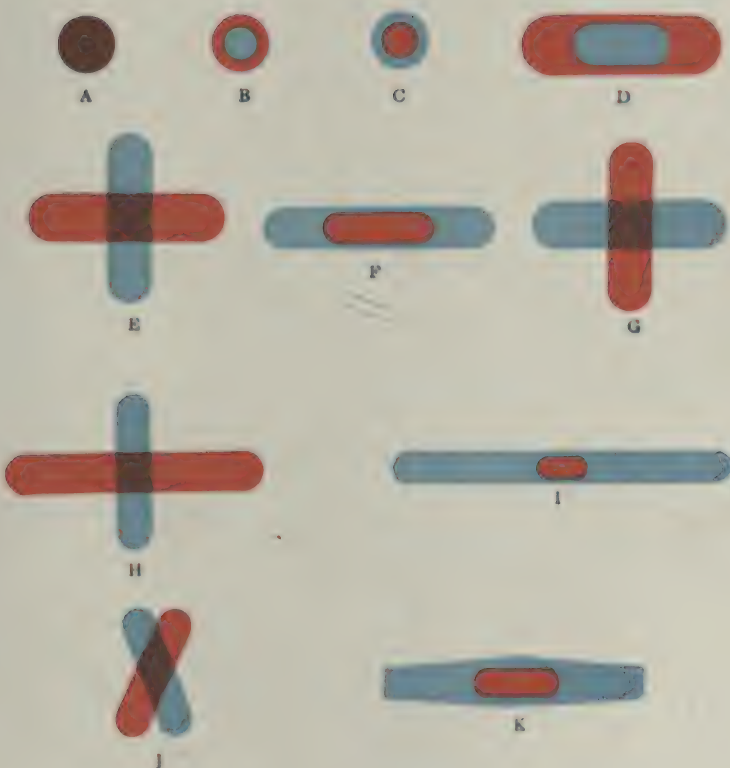
In *hypermetropic astigmatism* the flame, instead of being circular, will appear elongated, with a blue center and red extremities, and the convex cylinder that will restore the flame to its circular shape will be the measure of the astigmatism.

In *myopic astigmatism* the flame will also appear elongated, with a red center and blue extremities, and the concave lens that removes the elongation will be the measure of the defect.

In this diagram we see the red and blue rays in a parallel condition approaching and entering the eye; the blue rays, being more strongly refracted, meet in a focus just behind the line *H*, and the red rays, being least refracted, meet just before the line *M*. The line *H* indicates the position of the hypermetropic retina, where the eye perceives a blue center and a red outline *H′*, the latter being formed by the red rays, which have not yet come to a focus.

The line *M* indicates the location of the myopic retina, where


H E M
H' E' M'


A
B
C
D
E
F
G
H
I
J
K

the eye perceives a red spot (the focus of the red rays) with a blue border (see *M'*), formed by the rays which had previously met and crossed. The line *E* indicates the position of the retina of the emmetropic eye, where the red and blue rays cross each other and form the diffused violet tint *E'*.

In emmetropia the light will appear of a diffuse violet tint, as shown by *A*; in hypermetropia, of a blue center and a red border, as shown by *B*; and in myopia, of a red center and a blue border, as shown by *C*.

In simple hypermetropic astigmatism the flame appears elongated, with a blue center and red extremities, as shown by *D*, or a cross, as shown at *E*. In simple myopic astigmatism the elongated figure has a red center and blue extremities, as shown at *F*, or a cross, as shown at *G*. The appearance of the flame in mixed astigmatism is shown by *H* and *I*, and in irregular astigmatism by *J* and *K*.

RECAPITULATION: HOW TO EXAMINE THE EYE SYSTEMATICALLY.

This ninth chapter on the "Method of Examination" of the eye is a very lengthy one. It covers a wide field and embraces many matters of importance in the detection and correction of the various errors of refraction and anomalies of the muscles of the eye. In drawing this chapter to a close, it will be of advantage to the student to briefly rehearse the important points or steps to be taken in a systematic and thorough examination of the eye, or, in other words, present a brief outline and recapitulation of the chapter.

"It is said that any one can administer treatment in disease if he knows the disease, and 'there's the rub,' for to know the disease —in other words, to correctly diagnosticate—one needs only to be familiar with the symptoms in their various forms, but he must carefully examine; and to examine carefully he must not only have the necessary means of examination and various tests, but he must know how to employ them."

A complete examination of the eye embraces both *subjective* and *objective* methods: The former refers to the information gained from the patient's answers, while the latter refers to the information gained by the optometrist himself from an inspection of the conditions that are present and are appreciable to his educated senses, which includes an inspection of the head and face, the appearance of the eye, whether full or shallow, whether any difference in the two eyes or any asymmetry of the face, the size and dilatability of the pupils, and whether any convergence or divergence of the eyes exists.

The condition of the conjunctiva, of the cornea, of the aqueous humor, of the iris and pupil, are all noted in turn; after which the subjective examination is taken up by interrogating the patient as to his symptoms and obtaining the history of the case.

ACUTENESS OF VISION.

Next in order comes the determination of the acuteness of vision, which is accomplished by means of Snellen's test-letters, and is expressed by a fraction, the numerator of which denotes the distance at which the card is placed, and the denominator the number of the line which it is possible to read. As, for example, if the card is hanging at a distance of twenty feet, and the patient is able to read the No. 20 line, the acuteness of vision is expressed as follows: V. = 20/20. If only the No. 30 line or the No. 40 line can be read, then V. = 20/30 or V. = 20/40. It is desirable to have the test-card hanging at a distance of twenty feet in order to exclude as much as possible any effort of accommodation, as the refraction of the eye and the acuteness of vision are both determined at the same time.

The next step is to use the pin-hole disk in order to be able to determine whether the case is one of refractive error or organic disease of the eye. This is a simple and reliable method of diagnosis: If the disk improves vision, it is a case for glasses; if the disk fails to benefit the sight, the eye is beyond the optometrist's help.

The acuteness of vision, as expressed above, has reference to direct vision, or the vision pertaining to the yellow spot; in addition to which it is sometimes desirable to determine the indirect vision or that pertaining to the peripheral portions of the retina, which is best accomplished by means of a perimeter. The quantitative and the qualitative field of vision can be determined, and the extreme limits of the field of vision mapped out, and the existence of any possible blind spots can be discovered. As the different meridians of the eye are examined, the record can be transferred to a sheet of paper, and a diagram will thus be formed, showing the size and shape of the visual field.

WHEN VISION IS NORMAL.

The examination of direct vision in the emmetropic eye has shown it to be equal to 20/20. With vision as good as this, hypermetropia may possibly exist, but myopia and astigmatism may reasonably be excluded. Therefore, when the optometrist finds a case with a vision of 20/20, the question involuntarily arises in his mind, Is this a case of emmetropia, or is there any element of hypermetropia present in the case? This is to be determined by the acceptance or non-acceptance of convex lenses; the trial is first made with a very weak convex spherical lens, which is gradually increased in strength as the patient will bear, until the strongest lens is found which improves distant vision—or, at least, does not blur distant vision—and this lens will be the measure of the manifest hypermetropia. If all convex lenses are rejected, even the weakest (+ .25), the optometrist may reasonably conclude that the case is one of emmetropia.

WHEN VISION IS LESS THAN NORMAL.

If the patient's vision is found to be less than 20/20, it is due either to some error of refraction or to some organic disease. The pin-hole disk has already been used to determine this latter point. If due to a refractive error, it may be either hypermetropia, myopia or astigmatism. The test with convex lenses will determine whether or not the case is one of hypermetropia. If this is excluded, the optometrist next proceeds to determine whether myopia is present, which is done by testing the eyes with concave lenses. The restoration of the patient's vision to the normal standard by concave glasses proves the case to be one of myopia, and the weakest concave lens that affords a vision of 20/20 will be the measure of the myopia.

If concave lenses do not satisfactorily improve the vision, and if hypermetropia and myopia are excluded, the next thought of the examiner will be as to the existence of astigmatism. This is usually determined by means of Pray's card of astigmatic letters, or by the card of radiating lines; if some of the letters and some of the lines appear very much blacker and clearer than others, it is proof of the existence of astigmatism, which is then measured and corrected by cylindrical lenses.

If the defective vision is not due to any error of refraction.

and if the optometrist is unable to improve the vision by any glass, then an ophthalmoscope comes into play very nicely and appropriately to determine the seat and cause of the impaired vision, and, therefore, no optometrist's outfit can be considered complete unless it embraces this useful instrument, which formerly was reserved for physicians' use alone.

TABLE OF INDICATIONS.

Normal Vision, or a vision of 20/20,	means	Emmetropia, or, possibly, Hypermetropia.
Subnormal Vision, or a vision less than 20/20,	may mean	Hypermetropia. Myopia. Astigmatism. Amblyopia. Spasm of Accommodation. Cataract. Opacity of Cornea. Organic Disease of some of the Humors or Membranes.

MEASURING THE ACCOMMODATION.

Next in order comes the examination of the near vision, or the testing of the accommodation, or the measuring of the near point and far point. The nearest point at which the reading matter can be distinguished, that is, the closest point for which the eye can accommodate itself, is called the *near point.* The greatest distance at which the same type can be read may be considered for all practical purposes as the *far point,* although, strictly speaking, in emmetropia this is said to be at infinity. The distance between the near point and far point is called the *range of accommodation.* The force necessary to change the eye from its far point to its near point is called the *amplitude of accommodation.*

The accommodation is equal to a convex lens of such strength as would give to rays proceeding from the near point a direction as if they came from the far point, and in emmetropia the focus of this lens coincides with the distance of the near point. Therefore, in order to determine the amplitude of accommodation of the emmetropic eye, the optometrist has only to find the nearest point at which the patient is able to read the smallest sized type. It may also be determined by a concave lens, as the strongest concave lens through which an emmetropic eye is still able to see clearly at a distance is the measure of the amplitude of its accommodation.

In hypermetropia, the amplitude of accommodation which would be normally present in an emmetropic eye will be diminished by the amount of hypermetropia, and in myopia it will be increased by the degree of the defect that is present.

EXAMINATION OF THE CONVERGENCE.

Having measured the refraction and the accommodation, the optometrist now directs his attention to the function of convergence, which, it will be remembered, bears a constant relation to the accommodation. The function of convergence has reference to the directing of the two eyes to a single point which is situated nearer than infinity, and the angle of convergence is sometimes called the meter angle, when the eyes are directed to a point situated at a distance of one meter. This expresses the degree of convergence which is required to maintain binocular vision at this distance, and is employed as a unit from which to express other degrees of convergence. In this case the metrical angle equals one, and is expressed, C. = 1.

If the object looked at be situated at half a meter distance, the angle of convergence will be twice as large as when at one meter, and is expressed or written, C. = 2. If at one-third a meter, the angle of convergence is correspondingly increased, and then, C. = 3. If, on the other hand, the object be situated at a greater distance than one meter, say at two meters or four meters, the angle of convergence will be diminished in proportion, and then we have, C. = ½, or, C. = ¼. The angle of convergence diminishes in this same proportion as the distance of the object is increased, until finally, when infinity is reached, the angle of convergence will have disappeared and the visual lines become parallel.

In emmetropia, for distances nearer than twenty feet, the number of meter angles of convergence required bears a constant relation to the number of dioptres of accommodation called for. At a distance of one meter, 1 D. of accommodation is required to focus the image on the retina; and at the same distance one meter angle of convergence is needed for binocular vision. At a distance of half a meter, there is 2 D. of accommodation and two meter angles of convergence.

TESTING STRENGTH OF MUSCLES.

The function of convergence being dependent on the action of the internal recti muscles, it becomes an important matter to know how to determine the strength of these muscles, and also to detect any weakness of them and of the other ocular muscles. This is best accomplished by testing the muscles with prisms. When a prism is held before one eye, the eye will have to turn in the opposite direction from which the base of the prism is placed in order to preserve binocular vision.

The power of divergence, of the strength of the external recti muscles, is measured by the strongest pair of prisms, bases in, which will not cause double vision of a distant object. The normal average power of the external recti muscles is represented by a prism of from 8° to 10°.

The power of convergence, or the absolute maximum of convergence, or the strength of the internal recti muscles, is determined by finding the strongest prism over one eye, or the strongest pair of prisms over both eyes, bases out, which will not destroy single vision of an object held as close to the eyes as the accommodation will permit. The normal power of convergence, or the average strength of the internal recti muscles, is represented by a prism of from 20° to 30°.

TESTING FOR MUSCULAR INSUFFICIENCY.

In testing the ocular muscles, in order to detect any insufficiency, the first step is to dissociate the functions of convergence and accommodation, which is accomplished by a prism placed in a vertical position. A very weak prism will suffice for this purpose (2° or 3°), and when vertical diplopia is produced in this way, any insufficiency of the internal or external recti muscles becomes apparent by a lateral displacement of one of the images.

In testing the muscles at a distance of twenty feet or more, a candle-flame is used; at a near distance, the dot and line is to be preferred. It is customary to use a prism of 10°, which is placed over one eye with its base up or down; vertical diplopia is at once produced, and if the two images are in the same vertical plane, the muscles are assumed to be of normal strength. But if there is a lateral deviation, it is due to the existence of muscular insufficiency. If the diplopia is homonymous, the insufficiency is located in the external recti muscles, a condition of esophoria. If the diplopia is crossed, the insufficiency is located in the internal recti muscles, a condition of exophoria. In the first case, the degree of prism, base out, and in the second case, the degree of prism, base in, necessary to restore the images, to the same vertical line are the measure of the insufficiency.

This test can be varied by the use of the Maddox rod or the Maddox groove, either of which, placed before the eye, elongates the flame into a long, narrow streak of light, the position of which, in relation to the normal flame, as seen by the other eye, will indicate the presence, or absence, of any muscular insufficiency. If the streak of light is directly over the flame, the muscles are normally balanced—a condition of orthophoria. If the line of light is to one side or the other of the flame, muscular insufficiency is proven—a condition of heterophoria.

The Maddox rod or groove is placed before the eye in the horizontal position when it is desired to test the internal and external recti muscles, and in the vertical position when the superior and inferior recti muscles are under examination, which means that the line of light should be at right angles to the deviation which it is desired to measure. The degree of the heterophoria and its nature will be determined by the strength of the prism and the position of its base, which are required to bring the line of light directly over the candle-flame.

In addition to the tests for determining a weakness of any of the recti muscles, we have a test for detecting compound muscular defects (that is, of both the vertical and horizontal muscles), and, also, for examining the oblique muscles. This test is made by a double prism, which consists of two prisms set in a rim, with their bases together.

In using this test with both eyes open, three images are seen, and the position of the middle image will indicate the presence or absence of any muscular insufficiency, and what muscles are affected, if any. In this way can be detected an insufficiency of any one of the recti muscles, or of either of the oblique muscles.

PRACTICAL POINTS.

In examining the acuteness of vision and determining the refraction of the eye, the card of test-letters should be so hung that the best possible light may fall upon it.

In determining the refraction of an eye, the test should always commence with *convex* lenses.

Each eye should be tested separately, commencing usually with the right eye, or with that eye that possesses the greater acuteness of vision, while the other eye is excluded from vision by an opaque metal disk placed in the trial-frame.

After having ascertained the refraction of each eye separately, the two eyes are then to be tried together; and it will be found that binocular vision is better than that of either eye separately; with the two eyes, stronger convex glasses will be accepted in hypermetropia, and weaker ones may be required in myopia, than the test of a single eye would indicate.

CHAPTER XI.

PRESBYOPIA.

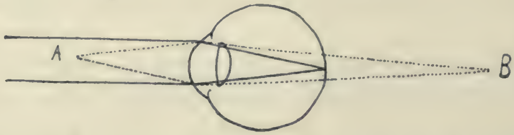
Before entering upon the consideration of the subject of presbyopia, it may be well for the student that a little attention be given to the accommodation of the eye. As is the case with all optical instruments, so the dioptric apparatus of the eye, when in a state of repose or when not changed by muscular effort, can receive distinct images of objects only when they are situated at one and the same distance. When the distance is changed the apparatus must be modified, or the distinctness of the image will be marred.

In a condition of perfect repose the eye exercises its minimum power of refraction, and is then adapted to the greatest distance at which it is able to see, that is, its far point, and cannot then see distinctly those objects which are close at hand. In this condition of inaction of the accommodation, the *emmetropic* eye is adapted for infinite distance, or for the parallel rays which proceed from, and represent, infinity; the *hypermetropic* eye is adapted for a point beyond infinite distance, that is to say, for rays converging toward its far point situated at a distance; the *myopic* eye, whose far point is situated at a certain fixed distance in front of it, is adapted for that distance, or for the diverging rays proceeding from that distance. In each of these cases the parallel rays, the converging rays and the diverging rays are respectively united on the retina, and form a perfect image there without any effort of the accommodation.

An eye, when in a condition of repose, as above, and adjusted for its far point, cannot distinctly see objects at any nearer distance, because its dioptric apparatus is too feeble to bring the more diverging rays proceeding from nearer objects to a focus on the retina. An example may be taken of an emmetropic eye: Its far point being situated at infinity, the eye is adapted for the parallel rays that proceed from that distance, and rays from no other point are focused on the retina.

In the figure on page 342, parallel rays are united in an exact focus on the retina, while the divergent rays proceeding from a near point, as at A, are united behind the retina at the point B. In order that these divergent rays may be united on the retina, it is necessary either to render them parallel, or to increase the refracting power of the eye to such a degree that it will unite them on the retina instead of at B.

If there is placed in front of the eye a convex lens of such strength that its focus would be at A, it would render parallel the rays coming from A, and make them the same as if they came from infinite distance. The emmetropic eye, by the aid of this glass, will therefore see as well at the short distance A as it does at infinite distance without any glass, in both cases with the eye at rest, and without any effort of accommodation.



In this way the focus of the eye could be changed and its vision adapted for objects at different distances, but outside of this the fact remains that the eye is able to see close at hand as well as at a distance, and that, too, without the intervention of any convex lens. It is necessary, however, that a certain very short time elapse in passing from the fixation of an object at a distance to one near at hand, and with this change there is oftentimes a consciousness that the eye makes a certain effort in altering its point of fixation. In making this change, the effort exerted has added to the dioptric system of the eye the convexity necessary to enable it to see objects close at hand. This increase in the refracting power necessary to change the adaptation of the eye from a far point to a near point, an increase which the convex lens accomplished when the eye was in a condition of repose, is now effected in the eye itself. This is accomplished by the crystalline lens, which undergoes a change of form necessary to accommodate the eye for objects close at hand, which change consists in an increase in its convexity, and, therefore, in its refractive power.

The function of accommodation, or the change in the adjustment of the eye for vision at different distances, is effected by means of the action of the ciliary muscle, which, by its contraction, causes the ciliary body to advance. The ciliary ligament is thereby relaxed, and the lens, which had been more or less flattened by its tension, is left to its own inherent elasticity and assumes a more convex shape anteriorly, while the posterior surface, incased in the vitreous humor, preserves its form almost unaltered.

The closest point for which the eye can accommodate itself is called the *near point*. The distance between the far point and the near point is called the range of accommodation. It is the distance over which the eye has command by the aid of its accommodation. The force necessary to change the eye in its adaptation from its far point to its near point is called the amplitude of accommodation. Consequently, the amplitude of accommodation is necessarily represented by the difference in the refractive power of the eye when in a state of complete rest, and when at its maximum of accommodation.

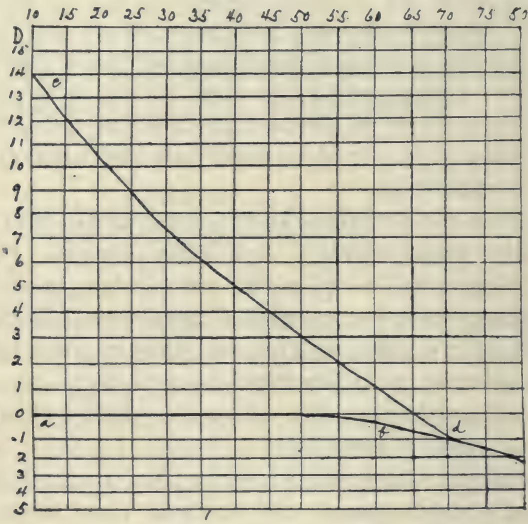
Now, since the accommodation has the same effect as a convex lens which would enable the eye, when deprived of its accommodation, to see at its near point, we are able to express the power of the accommodation by the number of this lens. The accommodation is therefore equal to a convex lens of such strength as would give to rays, proceding from the near point, a direction as if they came from the far point. Now the question occurs—What will be the strength of such lens?

As has already been stated, the focus of the lens of the emmetropic eye should coincide with the near point, since it should render parallel the divergent rays proceeding from that point. Its focal distance is, therefore, equal to the distance which separates the near point from the eye. If this distance is ten inches, the lens will have a refracting power of 4 D., and the amplitude of accommodation will equal 4 D.

The whole of this refracting power serves to adapt the eye for positive points situated within infinite distance. In order to determine the amplitude of accommodation of an emmetropic eye, we need only find the shortest distance at which the person can read the smallest printed characters. This distance is the focal distance of the lens corresponding to the amplitude of accommodation.

As has already been stated, the accommodation depends, on the one hand, on contraction of the ciliary muscle, and on the other hand, on the elasticity of the lens. As age advances, the ciliary muscle loses, by degrees, its power of contractility, and in like manner the lens loses its elasticity. These two factors, the loss of strength of the ciliary muscle and the increasing hardness of the lens, have, necessarily, a restricting influence upon the accommodative power.

When we come to think of it, it does seem somewhat strange that this diminution of the accommodative power does not wait



for the usual decrepitude that accompanies and constitutes old age, but that it begins at a time when all the other faculties are progressing in their development. Already, at the tenth year, the accommodative power begins to weaken and its amplitude to diminish.

Donders, who discovered this fact and established the laws that govern it, has prepared a diagram which represents the amplitude of accommodation at the different periods of life.

The figures on the horizontal line of the diagram indicate the ages, and those on the vertical line, to the left, the corresponding dioptres of accommodation. The curve *a b* corresponds to the refraction of the eye in a condition of repose, or, in other words, when at its *minimum* of refraction; that is to say, to the refracting power which the eye represents when adapted for its far point.

As will be seen in the diagram, this does not change up to the age of fifty years, but from that time on it diminishes; the emmetrope becomes hypermetropic; the hypermetrope more hypermetropic; and the myope loses a part of his myopia, and may become, according to its degree, emmetropic, or even hypermetropic.

The curve *c d* indicates the maximum of refraction of which the eye is capable, that is to say, the sum of the refracting power which the eye represents in a state of repose, and what it is able to add to itself by putting into play all its power of accommodation, or, expressed still differently, the refracting power which the eye possesses when it is adapted to its near point.

As can be seen by the diagram, the positive refracting power of the eye diminishes gradually, and becomes, from the age of sixty-five, feebler than the minimum of refraction was in the preceding years. In spite of this, however, there still remains some accommodative power so long as the two curves do not meet, because the passive refraction of the eye also diminishes from the fifty-fifth year. It only ceases at the age of seventy-three years, when the two curves meet.

The amplitude of accommodation is represented for each age by the number of dioptres, comprised between the two curves, on the vertical line corresponding to the age, which means that the amplitude of accommodation is represented by the difference in the refraction of the eye when in a state of absolute rest and with its accommodation completely relaxed, and when the eye is exerting its entire force and its accommodation is at the greatest tension. By following these lines in working out the problem, there has been prepared the following

TABLE:

Age	Amplitude of accommodation	Age	Amplitude of accommodation.
10 Years.	14 D.	45 Years.	3.5 D.
15 "	12 "	50 "	2.5 "
20 "	10 "	55 "	1.75 "
25 "	8.5 "	60 "	1 "
30 "	7 "	65 "	0.25 "
35 "	5.5 "	70 "	0.25 "
40 "	4.5 "	75 "	0.00 "

The amplitude of accommodation is just the same in an eye with an error of refraction as in a normal eye, and, therefore, the figures in the table apply equally to all the errors of refraction to which the eye is subject, and to all degrees of the various errors. The amplitude of accommodation is the same in all these defects, but the positive refracting power of the eye is not the same, but it is composed of, or equal to the sum of, the refraction which the eye represents when in a condition of repose and with its accommodation at rest, and that which can be added by the strongest effort of its accommodation.

In emmetropia, and in emmetropia only, is the positive refracting power of the eye (that is, the strongest refracting power which the eye is able to assume by the greatest effort of its accommodation which adapts it to its near point), identical with, and equal to, amplitude of accommodation.

In hypermetropia there is no such thing as perfect repose for the eye, nor can the accommodation of the hypermetropic eye ever be at rest, because clear vision, even at a distance, is obtained only by an effort of the accommodation. The far point of such an eye is situated beyond infinity, and, consequently, it is a negative quantity. Here a portion of the amplitude of accommodation must be used to correct the hypermetropia and to adapt the eye for infinity, and, therefore, the positive refracting power of a hypermetropic eye is equal to the amplitude of its accommodation, diminished by the portion that is necessary to adapt it for infinity.

In myopia, on the other hand, the accommodation is but little needed, because the eye is adapted for its far point, which is situated at a certain definite distance; and, when adjusted for this far point, the accommodation is at rest. The far point of such an eye being situated at a finite distance, its condition of repose is positive, or represents a quantity of positive refraction. Here, then, a portion of the positive refracting power of the eye is supplied by its optical condition, and augments its amplitude of accommodation by that amount (instead of subtracting from it, as in hypermetropia), and, therefore, the positive refracting power of a myopic eye, that is, its total amount, is equal to the sum of the amplitude of its accommodation and that power of refraction which is represented by the eye in a state of repose.

Suppose we represent the positive refracting power of the eye by the abbreviation *pos. ref.*, and the amplitude of accommodation by *amp. acc.*, and the condition of repose, when the accommodation is at rest, by *rep.* From this we prepare the following

TABLE:

Emmetropia. *Pos. ref.* = *amp. acc.*
Hypermetropia. *Pos. ref.* = *amp. acc.* less *rep.*
Myopia. *Pos. ref.* = *amp. acc.* plus *rep.*

The distance of the near point from the eye is equal to the focal distance representing the total amount of the positive refracting power (*pos. ref.*). In view of this fact, it follows that the near point is not always situated at the same distance in the different states of refraction. Even when the amplitude of accommodation is the same the near point will always be farther removed in hypermetropia, and brought closer in myopia, than in emmetropia.

As an example, we will take an emmetropic person twenty years of age. A reference to the table shows that he possesses 10 D. of accommodation, and, therefore, the distance of his near point from the eye will be 10 centimeters (100/10 = 10), or four inches.

A hypermetropic person of 4 D., at the age of twenty, will also possess an amplitude of accommodation of 10 D., but his near point will not be at four inches, as in the case of the emmetrope, but will be further removed, according to the following formula:

Pos. ref. = *amp. acc.* less *rep.*
Pos. ref. = 10 D. — 4 D. = 6 D.

This makes the distance of the near point in a hypermetrope of 4 D. at 16 centimeters (100/6=16), or six inches.

On the other hand a myope of 4 D. also possesses, at the age of twenty, an amplitude of accommodation of 10 D., but his near point will not be at four inches, as in the emmetrope, nor at six inches, as in the hypermetrope, but will be much nearer in either case, according to the following formula:

Pos. ref. = *amp. acc.* plus *rep*
Pos. ref. = 10 D. — +4 D. = 14 D.

This places the distance of the near point in a myope of 4 D. at 7 centimeters (100/14 = 7), or a little less than three inches.

Therefore, the distance of the near point in emmetropic persons corresponds to the focal distance of the lens which represents its amplitude of accommodation, according to the following

TABLE:

Years	Amplitude of accommodation.	Distance of near point.	Inches.
10	14 D.	7 cm.	3
15	12 "	8 "	3 1/5
20	10 "	10 "	4
25	8.5 "	12 "	5
30	7 "	14 "	5½
35	5.5 "	18 "	7
40	4.5 "	22 "	9
45	3.5 "	28 "	11
50	2.5 "	40.5 "	16
55	1.75 "	57 "	23
60	1 "	100 "	40

In order to determine the distance of the near point in patients with defective vision, we ascertain the maximum power of refraction which the eye possesses (*pos. ref.*), and the focal distance of the lens which represents this will be the distance of the near point. In order to determine the positive refracting power in hypermetropia, we must subtract from the *pos. ref.* of emmetropia the number of dioptres which represents the degree of the hypermetropia, while in myopia we must add to the *pos. ref.* the number of dioptres which represents the degree of myopia.

The recession of the near point is so constant and regular that some authorities think they are able to determine from it, with considerable precision, the age of the individual by taking into account the state of refraction of the eye.

The near point of distinct vision, which, in childhood, is very close, gradually recedes with each year of life, this recession commencing as early as the tenth year, and steadily and constantly progressing, as can be seen by reference to the above table.

In regard to this table, it may be said that the figures do not invariably represent the total amount of accommodation it is possible for the eye to make by the strongest effort it can exert. For instance, at the age of forty-five, it is stated that the nearest point of clear and comfortable vision is at eleven inches, but in such a case it may be found that the eye, by an extraordinary effort of its accommodation, will be able to read for a very short moment at a closer point—say at, perhaps, ten inches.

As the near point gradually and steadily recedes farther and farther from the eye, it must finally pass beyond the distance at which we are accustomed to read and write and use our eyes for the ordinary occupations of life. When the near point has passed this limit, it is evident we will begin to be restricted in our work. Even at a time when the total effort of our accommodation yet suffices to keep the near point at the customary position, work at that distance must soon become very fatiguing, and even impossible, because it is accomplished only by the aid of the maximum contraction of the ciliary muscle.

The condition of the eye when the near point has passed beyond the usual distance for reading and writing and work, is a matter of considerable importance; and from the fact that this diminution in the power of accommodation does not cause any inconvenience until middle age is reached, and near vision continues satisfactory up to that time, the name presbyopia has been given to this condition, which word is made up of two Greek words meaning *old vision*. It means that the ciliary muscle is no longer equal to the task of affording clear vision at near distances.

For forty years and more this little muscle of accommodation has been brought into constant use during our waking hours, and has been an indispensable companion in all our occupations. Only by its use have we been able to read the daily news and keep ourselves informed of occurrences of interest at home and abroad. Only by its assistance have we been able to gain an education and store our minds with useful knowledge, or while away some tedious hour by a perusal of the latest novel. Only by its aid are civilization and the spread of intelligence possible; and without its beneficent offices we would be relegated to the condition of the untutored savage.

But, finally, this prop on which we have been accustomed to lean for so many years begins to weaken, and seems loath to still perform its function with its old-time fidelity, and we are forced to realize that we can no longer depend on it for near vision in our ordinary occupations of life, and we are then compelled to look elsewhere for that assistance which Nature is beginning to refuse us.

In searching for the time when glasses were first used for the improvement of vision, we are carried back to the thirteenth century, when we find they were employed to assist the vision of old people for work close at hand, or for the relief of the condition which we now call presbyopia. It is said that Roger Bacon.

who was the professor of philosophy in the University of Oxford, indicated how much benefit old men might derive from looking at letters through a convex lens, and mentioned the magnifying properties of such lenses.

The use of the convex lens as a magnifying glass, and the making of binocular spectacles for use in overcoming the deficiencies of the eyes induced by age, imply a great stride in the development of the optical art. In comparison with the elegant and finely finished spectacles and eyeglasses that are produced by the manufacturing optician of the present day, those clumsy, ill-shaped spectacles of the olden time seem very crude indeed, and we are almost disposed to sneer at them; and yet we cannot doubt that they were of the greatest value to the studious men of that day, and, indeed, we cannot help but wonder how people got along without them previous to that time. As night now is made almost as bright as day by the blare of electric lights of numberless candle-power, the same wonder arises how our forefathers lived and progressed and accomplished their wonderful strides by the aid of pine knots and tallow dips. But, then, books and magazines and newspapers were not a part of the daily life of that day, and, therefore, the same necessity for the constant use of the eyes for letters did not exist, nor was the necessity for artificial aid to the eye felt as at the present time.

Now they are a necessity and a comfort to the aged members of every household; "for it is not too much to say that through the aid of spectacles we continue in the enjoyment, even in old age, of one of the most noble and valuable of our senses. They enable the mechanic to continue his labors, and the artist to display his skill, in the evening of life; the scholar pursues his studies by their help, adding to the knowledge of others, and recreating his own mind with intellectual pleasures, thus passing days and years in satisfactory occupation that might otherwise have been devoured by melancholy, or wasted in profitless idleness."

"This return to juvenility of sight is one of the most agreeable experiences of middle age. It cannot be too generally understood that spectacles, instead of being a nuisance or an incumbrance, or an evidence of bad sight, are, to the presbyope, a luxury beyond description, clearing outlines which were beginning to be shadowy, brightening colors which were beginning to fade, and instantly restoring near vision to a point from which, for ten or a dozen years previously, it had been slowly and imperceptibly, but steadily, declining."

Many persons strive to fight against the approach of presbyopia, and vainly imagine they can do something by their own effort to retard or delay its coming. But it is a vain and foolish struggle against the inevitable. Just as sure as the sun will rise to-morrow morning and set to-morrow evening, just so sure will the eye begin to fail, for reading vision, as the person reaches middle life. It is not only useless, but positively harmful, for any man to fight against Nature in regard to the changes it affects in the human eye, and the sooner people can be convinced of this fact, and can be induced to accept the assistance which art offers in place of waning natural powers, the better for them. They may resort to imprudent artificial means to neutralize the approach of age, and, in some ways, may succeed in deceiving others, and even themselves. But, as regards failing eyesight for reading, it cannot safely be disregarded, and any effort to deceive others will result in more badly deceiving themselves.

When the optometrist speaks of these matters, and urges his friends and customers to accept the inevitable, and tries to convince them of the absolute necessity of commencing to wear glasses just as the first symptoms of presbyopia manifest themselves, it may, at first sight, seem as if he was talking selfishly, and from self-interest, and solely for his own benefit. But, as the public becomes better educated in these matters, they will begin to realize that the benefit is on their side just as much as, and more so than, on the optometrist's, and they will be forced to admit that the spectacle man knew what he was talking about; and, until that time, the optometrist must be willing to suffer misapprehension, content with the knowledge and consciousness of his own rectitude in the matter. Every day some individual learns, from sad experience, and, perhaps, when too late, that he has trifled with and neglected his sight, until his eyes have been permanently and seriously injured.

It is possible for the use of glasses to be deferred for quite a long time after they are really needed; but the delay is accomplished only at great cost, and has to be paid for in some way, sooner or later, and with the addition of the highest rate of compound interest.

An illustration may be used of a costly engine, finely finished and nicely adapted in all its parts; constant oiling keeps this delicate piece of mechanism running smoothly and without the slightest evidence of friction, and, apparently, without any wear and tear or injury to any of its parts. Suppose the oiling was neglected for a day or two; the engine would not refuse to run, but would continue to perform its functions, but with considerable more of an effort. The oiling may still be neglected and the engine still continue to run and accomplish its work, but at the expense of so much effort and so much friction that the finely balanced piece of mechanism is soon irreparably damaged, and rendered worthless.

CHANGES THAT TAKE PLACE IN THE EYE WITH THE ADVANCE OF AGE.

The acuteness of vision for distant objects must vary, more or less, with the degree of transparency of the atmosphere. So, also, the distinctness of the retinal images must vary, more or less, with the degree of transparency of the refractive media of the eye. This transparency of the humors of the eye is most perfect in childhood, a fact which can be ascertained by the use of the ophthalmoscope, and it gradually and slightly diminishes with the advance of age. Therefore it follows, as a natural sequence, that the acuteness of vision must be greater in childhood than at any other period of life.

The diminution in the transparency of the refractive media of the eye is evidenced by a lack of the natural lustre of the cornea, and the formation of the arcus senilis near its margin; by the formation of folds of the membranes of the vitreous and by the increase of the number and size of the muscæ volitantes; the layers of the crystalline lens become turbid and its nucleus assumes a yellowish tint, and the retina, also, becomes slightly opaque. An authority says, "The diminution of transparency of the refractive media progresses with such uniform regularity with advancing years, that practiced ophthalmoscopists are able to approximate the age of the patient by observing the clearness with which the fundus of the eye can be seen." This is a strong statement, and one that almost staggers belief; but the possibility of such a thing serves to prove, not only that there is a loss in the transparency of the media, but that this loss is a matter of steady and gradual growth.

Some changes may also occur in the sclerotic, choroid and iris; the pupil, also, gradually lessens in size, and thus diminishes the quantity of light admitted into the eye, which decrease of light must be compensated for by an increase in the degree of illumination. Senile changes also take place in the optic nerve, whereby its conductive power is diminished and its perceptive power also blurred, similar changes occurring in the retina.

The changes which occur in the eye all tend to cause a decrease in its refractive power and a lessening of its range of accommodation. The crystalline lens becomes firmer and harder, and, as the lines of separation between its different layers become less distinctly marked, the lens appears to become more homogeneous, and also somewhat flatter, and, as a consequence, it loses part of its refractive power. The increase in the firmness of the lens makes it more difficult to be acted on by the ciliary muscle in the production of the degree of curvature of its surfaces necessary for the distinct vision of small objects close at hand, and in this way diminishes the range of accommodation.

The gradual diminution in the refractive power of the eye proceeds until the time arrives, at middle age or later, when its condition has changed to one of acquired hypermetropia. Many of these changes in the eye commence in childhood, but their progress is so slow that they escape notice. The defects can, in earlier years, in a great measure, be partly neutralized by an increase in the illumination and by holding small objects farther from the eyes, until, finally, they become sufficiently manifest to interfere with the function of vision for objects close at hand, and the unassisted eye is no longer able to perform its functions in the ordinary occupations of life.

CHANGES IN THE LENS.

While the changes that take place in the eye with the advance of age are many, yet the principal cause of the diminished refraction of the eye and of the approach of presbyopia must be sought for in the changes that take place in the crystalline lens.

There was at one time an erroneous theory prevalent that the cause of the diminution of the accommodative power was due to a flattening of the cornea, and this opinion was believed and taught by all the older physiologists, until the investigations of modern science proved its fallacy, and it may even yet be found in some of the popular treatises on optics, which are used in elementary teaching. But the measurements that have been made of the convexity of the cornea seem to prove the utter falsity of this teaching, and that if there is any change in the curvature of the cornea, it is in the direction of becoming slightly more convex. Hence, some other cause must be sought for to explain and account for the changes that take place in all eyes, and which, even in childhood, cause the near point to gradually recede, until, finally, after middle age, emmetropia gives way to acquired hypermetropia; and this cause is found in the changes which the crystalline lens undergoes.

THE CRYSTALLINE LENS.

The crystalline lens is a lens-shaped body (as its name would indicate), and in health is perfectly transparent. Its anterior and posterior surfaces are both convex, or, in other words, it is a biconvex lens; but the curvatures of both surfaces are not equal, the posterior surface having a much stronger curvature than the anterior. The lens lies in a depression in the vitreous humor made to receive it, and is directly behind the pupil and in contact with the pupillary edge of the iris.

The crystalline lens consists of a transparent capsule and the lens substance proper. The curvature changes with age, it being more convex in childhood, and becoming gradually flatter with the advance of age. Its consistency is much firmer than that of the vitreous body. Its transparency is gradually changed to a yellowish-amber tint with advancing years.

In childhood the lens is soft, and quickly yields to the action of the ciliary muscle, changing its form and convexity with the greatest ease. The nucleus of the lens is somewhat firm, but the balance of the structure is soft and pliable, the softness and elasticity increasing more and more toward the periphery. The refractive power of the crystalline lens is at its greatest in childhood, at which time, on account of its softness and elasticity, which are particularly noticeable in its outer layers and peripheral portions, its convexity is easily increased by the action of the ciliary muscle to the highest possible degree.

As years pass by and age creeps on, the outer layers of the lens gradually increase in firmness until they approach the consistency of the nucleus, while the lines of separation between the different layers become less and less marked, making the lens more homogeneous in structure, both of which causes act to diminish its refractive power. Its increased firmness renders it less yielding to the action of the muscle of accommodation; consequently, when the usual degree of muscular force is applied, it produces much less effect on the firmer and more uniformly homogeneous crystalline structure than on the softer laminated lens of youth. In addition to the inability of the ciliary muscle to produce the same degree of convexity of the lens as in childhood, there is also a diminution in its actual refractive power.

Senile changes take place in all eyes, the same in myopic and hypermetropic as in emmetropic eyes; but, of course, the changes are more marked and more noticeable in hypermetropic eyes, and less manifest in myopic eyes. At this time the myope has the greatest advantage, because in myopia there is an excess of refractive power in the eye, and the far point of distinct vision is uncomfortably close. The presbyopic changes, in diminishing the refractive power of the eye and in removing the reading point to a more convenient distance, tend only to place the eye in a more normal condition for satisfactory and comfortable use.

DONDERS' OPINION.

It is for these reasons that Donders gives his preference to this myopic condition of refraction, and as he has been one of the masters in the science of optics, and as his great work on "Refraction and Accommodation" has been the source from which much of our knowledge has been drawn, we will give his words on this subject *verbatim:*

"Finally, should the question be proposed whether emmetropia is the most desirable condition: As concerns myself, I should give the preference to a slight degree of myopia, and I shall subsequently state my reasons for doing so.

"The inconvenience to youth from a slight indistinctness of more remote objects is more than compensated for by the improved vision of middle and advanced life. Herein the myope finds a compensation for what he loses with reference to the vision of remote objects. The advantage is not small. Up to the sixtieth, or even the seventieth, year of our age, not to need spectacles in order to see accurately whatever comes immediately under our eyes is a great privilege.

This privilege belongs to a myopia of from 1/10 to 1/14 (3 D. to 4 D.), in which the eye is not threatened with any special dangers. With slighter degrees of myopia a good deal of this privilege is still enjoyed. This is a condition which may well be envied by emmetropic eyes. I never found a normal eye which participated in the same advantage. Many persons, however, suppose they are so highly privileged. Almost daily it occurs that at fifty-five years of age the distance of the far point lies at only from eight to ten inches, and spectacles are not thought of. Such people consider themselves a lucky exception. They are extremely proud of their sharp sight. The inquiry whether they are near-sighted is answered in the negative, with a smile of self complacency.

"At a distance of twenty feet hang Snellen's letter-tests; lines 20 and 30 they do not recognize; 40 not at all or scarcely; 50 and 60 are the first which are easily recognizable to them. Not until they try glasses of — 1/50 or — 1/36 do they well distinguish line 20, or at least 30, with accurate contours. Reluctantly they acknowledge themselves beaten."

There are many persons met with in our daily experience who are able to read fine print, without convex glasses, at fifty or sixty years of age, and who regard it as an evidence that their eyes have escaped the customary senile changes. To such persons the above extract from Donders would be interesting reading and a revelation. They were myopic in youth, although they were probably unaware of the fact. Persons frequently discover that their eyes are near-sighted by accidentally trying on a pair of concave spectacles, and they are surprised to find that distant vision is greatly improved, so much so that they are often impelled to ask the question if other people can see as clearly at a distance as they do after having placed before their eyes a pair of concave glasses, such a bright and new world having been opened up to them.

It often happens in the experience of many an optometrist, while ascertaining the acuteness of vision of a patient sitting in the chair and looking at the test-card hanging twenty feet away, that an accompanying friend expresses astonishment that the patient should be able to read the No. 20 line at twenty feet. He finds he is unable to do it, and yet, if you ask him if he is near-sighted, he says no, he can see as far as any one. When he is placed in the chair, after the patient has vacated it, and he is given concave glasses of 1 D. or 2 D., he is at once enabled to read this line with the greatest ease, and he learns, for the first time, that his eyes are myopic. At fifty-five or sixty years of age he will be able to read and write and perform all of the ordinary occupations of life without the assistance of convex glasses, and if he had not accidentally learned that his eyes were myopic, he would naturally have thought that they had escaped the usual senile changes.

PRESBYOPIA NOT ABNORMAL.

Presbyopia is not an optical defect—it is a physioligical change. It should not be considered a disease, or a defect, or a departure from a normal condition. It is simply the result, and an invariable accompaniment, of old age, just as gray hairs, and other evidences of change and decay, make their appearance at the usual time, to show that we are gradually advancing in years. Presbyopia should, therefore, be looked upon as a natural condition of the eye, or a natural change in the condition of the eye, which is common to every person, and from which none can escape, except as it may be influenced by the refractive condition of each particular eye.

The state of the general health will frequently have a decided influence on the appearance of presbyopia, as a weakness of the ciliary muscle is often found in cases of general bodily weakness.

Presbyopia, in every case, will be modified by the refraction of the patient's eye. Hypermetropia increases it, intensifies it, and causes it to appear much earlier than otherwise; in fact, hypermetropia often exists without any special symptoms, and without causing any special discomfort, and only makes itself manifest as an early presbyopia. Hypermetropia causes a deficiency in the refractive power of the eye from the start, and as presbyopia also produces a gradual loss of the same refractive power with the advance of age, both conditions act in the same direction, and pull together, as it were, in producing the symptoms of presbyopia, which, in such a case, are augmented.

In myopia, on the other hand, we have a condition of refraction which tends to diminish and neutralize presbyopia, and to delay its oncoming until much later in life; and, in fact, when the myopia is of sufficient degree (— 4 D., or more), presbyopia may never occur, because, in such a case, the near point can never recede to an inconvenient distance. Myopia carries with it an increase of refractive power from the start, and, as presbyopia causes a gradual loss of refractive power, these two conditions pull in opposite directions, neutralizing each other and retarding the approach of presbyopia.

For these reasons it follows that no rules or tables can be prepared that will be of any very great practical value in the correction of presbyopia. If every eye possessed the same degree of refractive and accommodative power, and if every eye was equally affected by the inevitable senile changes, then every eye at a certain given age, the same for the whole human race, would begin to be presbyopic and would require the same glasses, in which case every age would call for a certain number of lens, and every year of life would indicate a certain definite increase in the strength of the glasses. Under such circumstances, the fitting of glasses for the correction of presbyopia would be as easy as rolling off a log, and would require no special optical skill or knowledge; in fact, the glasses could be selected by the patient himself and without any assistance.

But such is not the case, and the only proper rule that can be laid down for the guidance of the optometrist in the management of the cases of presbyopia that come to him for glasses, is to test each case carefully on its own merits, and determine the condition of the refraction for each person separately, and use this as the starting point from which to determine the glasses required, and without any reference to any ready-made tables on this subject.

WHEN DOES PRESBYOPIA COMMENCE?

This question carries with it the thought that presbyopia has a commencement, that it is not congenital, that it does not exist indiscriminately at any age of life, that it does not make its appearance at any irregular time, or from any indefinite cause, but that it is a defect or a change that is due to definite and natural causes, and that it does not come on unexpectedly or without warning; but that, sooner or later, with the exceptions that will be mentioned, it comes to every individual whose eyes are used for close or near vision of any kind.

Such being the case, the question very naturally occurs: At what age does presbyopia commence? As has already been stated, presbyopia comes on with the advance of years, and usually makes its appearance at what is termed middle age. Optical students.

pursuing a course of instruction, are frequently asked this question, and the usual answer is, "At the age of forty-five years."

Now, is this answer correct? It cannot be said to be absolutely incorrect; and yet, at the same time, it is not a complete and proper answer. It should be remembered that a gradual recession of the near point is one of the inevitable accompaniments of advancing years, and it is on this recession of the near point and its location that the commencement of presbyopia depends. The near point begins to recede very early in life (about the tenth year); but at this early age, and for some time thereafter, it has not receded to any inconveniently great distance, but is still near enough to the eyes as not to make any difference in their comfortable use, nor is reading or writing accompanied by any symptoms of asthenopia; and, hence, presbyopia does not commence until this near point has receded to such a distance as to make near vision (reading, writing and close work) inconvenient or impossible.

Then, in place of the question, At what age does presbyopia commence? the following query may be substituted: How far may the near point recede before painful and unpleasant symptoms are experienced in reading, or what is the farthest near point beyond which the symptoms of presbyopia become apparent, and the need of glasses, or of some artificial assistance, is experienced?

The answer to these questions has been determined more from practical experience, and the actual facts gained thereby, than from any nice scientific discovery or complicated mathematical calculation. It has been found that when the near point has receded beyond eight or nine inches, then near vision cannot be kept up with the same ease and comfort as before, and there is an uncontrollable desire to remove the work or paper farther from the eyes. The point of departure, then, we shall fix at eight inches, and the commencement of presbyopia in each case will depend on the near point having reached or passed this limit.

DEFINITION OF PRESBYOPIA.

Presbyopia, then, may be defined as that condition of the eye in which the near point has receded beyond this limit of eight inches, and the person has difficulty in using the eyes for close vision. It will be seen, from this definition, that the term presbyopia does not correspond to some well-defined condition, as do the terms myopia, hypermetropia and astigmatism.

This distance of eight inches, which has been fixed upon as the point of departure for presbyopia, is determined in an arbitrary manner, and yet it is not without reason. Some other distance could have been taken, and might, perhaps, answer equally as well (as seven and a half inches or eight and a half inches); but our great master, Donders, fixed upon eight inches, and it will be found that the greater number of authors use this same distance of eight inches. When the near point has receded to this distance, the individual first begins to experience difficulty in using his eyes for reading. Of course, a great deal will depend on the distance at which the person is accustomed to read or do his work. A man who is used to reading and holding his book at a distance of fifteen or eighteen inches will not feel the influence of age, or become presbyopic, nearly as soon as one who is in the habit of holding his reading as close to his eyes as ten or twelve inches. The latter will become presbyopic much sooner than the former, and yet the condition of the refraction may be the same in both cases.

SYMPTOMS OF PRESBYOPIA.

As a person with emmetropic eyes gets along in years and approaches his thirty-fifth milestone, he instinctively, in his reading, begins to seek print a little larger than he has been accustomed to, and he is apt to hold his book a little farther away from his eyes than formerly, and he looks for the best possible light on his work. These differences, however, may be so slight and the changes have been so gradual, as to have entirely escaped the patient's attention.

At forty years of age these changes have become more perceptible, and he begins to be conscious of the fact that he cannot see small objects as close or as well in a dim light as formerly; but, in spite of this, he manages to get along pretty well, and does not suffer any inconveniences from his eyes, and scarcely feels the need of any artificial assistance.

At forty-five years of age these changes have all become intensified, and the fact is forced upon him that reading by artificial light is attended with more or less difficulty. He thinks that the books and newspapers are not printed in as clear and legible type as formerly, and he complains that the light is very poor nowadays. In writing he finds difficulty in keeping on the pale ruled lines, but is one time above it and another time below it, because the line is really invisible. Letters like n and u are not sharply defined, and are scarcely distinguishable one from another. The head is thrown back and the book held at arm's length, and the effort is made, and persisted in, to continue the reading.

The strongest possible light is sought, and oftentimes the patient will place the lamp he is using between his eyes and his book. The light in this position serves a double purpose; it affords a greater illumination of the printed page, and at the same time the bright light, in shining into the patient's eyes, causes the pupils to contract, and so lessen the circles of diffusion by shutting out the circumferential rays, and thus assists vision.

The necessity for holding the book at so much greater distance causes the visual angle under which the letters are seen to be greatly diminished; consequently, the images formed upon the retina are smaller and cover fewer of the rods and cones of that membrane, and a strong light tends to increase the brightness of the retinal image, and thus, to some extent, to compensate for the smallness of the image.

In studying the symptoms of presbyopia and noting the changes produced in the crystalline lens, and the effect of such changes on the sight, we find that spherical aberration plays an important part, and it should be thoroughly studied and clearly understood.

SPHERICAL ABERRATION.

In spherical lenses the rays that pass through the *peripheral* portions of the lens are brought to a sooner focus than those passing through the more *central* portions, or, in other words, there is an excess of refractive power in the *marginal* portions as compared with the *central* portions. This excess increases with the distance from the center, and, therefore, the focal point for marginal rays is nearer than that for central rays. In such a lens there cannot be any common focal point for all the rays, and, this being the case, there cannot be a perfect image formed. It is blurred because the conditions for a perfect image are not fulfilled.

The use of a diaphragm, by covering the marginal parts of the lens, would greatly diminish the spherical aberration by shutting out all but the central rays; but though this would increase the clearness of the image, it would, at the same time, diminish its brightness, and, therefore, it can be used only when the light is very intense.

Complete prevention of spherical aberration can be accomplished only by increasing the refraction of the central portions of the lens, making it approximate that of the peripheral portions.

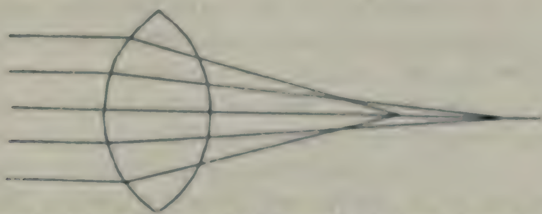
Following out this idea, the prevention or correction of spherical aberration can be accomplished in two different ways, viz.: First, by increasing the curvature of the central portions of the lens; second, by increasing the density of the lens, and, at the same time, its index of refraction. It is by means of the first method that art is able to overcome spherical aberration; while it is chiefly by means of the second method (or, perhaps, by a combination of both) that Nature prefers to accomplish the same purpose. It is an interesting study to observe the different methods adopted by art and by Nature to overcome the defects of spherical aberration.

In regard to the first method (that is, the increase of the curvature of the central portions of the lens), it has been determined by mathematical calculation that this increase of curvature must approximate that of an ellipse. It is justly considered one of the greatest triumphs of science to have been able to calculate the proper increase of this curve, and also of art to have carried out successfully the suggestions of science. Therefore, a lens, in order to make a perfect image, must be a segment, not of a perfect sphere, but of the end of an ellipsoid of revolution about its greater axis.

An *ellipse* is an oval figure bounded by a regular curve, and is formed by the intersection of a plane and a cone, when the plane passes obliquely through the opposite sides of the cone. An *ellipsoid*, in geometry, is a figure formed by the revolution of an ellipse about its axis.

To overcome spherical aberration by means of the second method seems to be beyond the reach of art, that is, by an increase in the density of the central portions of the lens. It has not been found possible to so graduate the increasing density of glass, from the periphery to the center, in such a proportion as to exactly neutralize this aberration. But what is impossible with art is quite feasible in Nature, for it is by reason of this method that the human eye is spared the interference with clear vision which spherical aberration would cause.

In the crystalline lens of the eye there is an increase in the density and in the refractive power of the lens from periphery to center. So marked and noticeable is this condition that the crystalline lens may be regarded as consisting of concentric layers, which increase in graded proportions in density and curvature from without inward, until when the central nucleus is reached, it is found to be a very dense and highly refractive spherule. The method of decreasing spherical aberration by means of a dia-



Illustrating spherical aberration, or the difference in the focus of central and marginal rays.

phragm is also made use of in the eye, as the iris, by changing the size of the pupil, acts in this way by cutting off the marginal rays and allowing only the central rays to pass.

It is evident to every student, and well known to every physiologist, that spherical aberration does not interfere with the clearness of the image formed in the human eye, and the result is accomplished by the methods mentioned above.

This laminated structure of the crystalline lens has also another very important use, in addition to the correction of aberration as mentioned above. In a homogeneous lens, that is, one of the same solidity throughout, and without any concentric layers of increasing density, the rays from the central part of the field of vision, that is, directly in front, would be brought to a perfect focus on the retina, and a clear image formed there; while the rays from the peripheral parts of the field of vision, that enter the eye under a certain degree of obliquity, would not be brought to a focus, and a more or less imperfect image would be the result. Consequently, the picture formed by such a lens would be clear and perfect in the center, but very indistinct as the margin is approached.

Now, this defect of a homogeneous lens is entirely corrected by the peculiar laminated structure of the crystalline lens. Therefore, the crystalline lens confers on the eye the capacity of distinct vision over a wide field, clear in the marginal as well as the central portions of the field, and without changing the position of the point of sight. This capacity of the eye has been called *periscopism,* a term of great significance, a clear understanding of which will enable the optometrist to appreciate the advantages of the so-called periscopic lenses.

SYMPTOMS OF PRESBYOPIA.

As the consistence of the crystalline lens increases with the advancing years, the density of the peripheral portions of the lens approximates that of the nuclear portions, and, consequently, the defect of spherical aberration becomes more and more apparent After reading the above paragraphs on the method which Nature adopts to overcome the defects of spherical aberration, that is, by an increase in the density and refractive index of the more central portions of the lens, so that they may simulate that of the peripheral portions, the optometrist is in a position to comprehend and appreciate the presbyopic changes in the crystalline lens, and how this increase in the density of the peripheral portions of the lens defeats and destroys and neutralizes Nature's method for the correction of aberration, and, consequently, the aberration becomes apparent because there remains no means for its correction, and this condition must be considered as one of the symptoms of presbyopia. Hence follow the advantages of a contraction of the pupil, which tends to overcome the aberration by shutting off the circumferential rays.

In childhood and youth the density of the crystalline lens diminishes from its center to its circumference, and, therefore, the peripheral rays are less refracted than they would be if all parts of the lens were of uniform density, and hence the circumferential rays would be united at nearly the same point as the central rays. In childhood and youth, also, we find the pupil to be quite large. and this dilitation of the pupil permits the peripheral rays to pass, which will still be united at the focus of the central rays, on account of the gradation of density of the lens, as mentioned above.

In good daylight, on clear days, and before the approach of twilight, the presbyope is still able to see fairly well; but he instinctively avoids fine print and seeks that which is large and clear. He finds there is some difficulty in reading and using his eyes by artificial light, and hence he seems disinclined to do much reading at night, except when compelled to do so, and then he seeks the brightest light and seats himself as close to it as possible.

Pretty soon this difficulty in reading, which at first was apparent only at night, becomes noticeable also in the daytime, and now near vision at all times, and under all circumstances, becomes difficult and painful, and the individual has a well-marked case of presbyopia. There can be no longer any doubt that the sight has failed and that the eyes are not as good and strong as formerly, and the consciousness of this fact is at last forced upon the person, and he is compelled to acknowledge that his natural sight is not sufficient for his every-day needs. This is rather a humiliating acknowledgment for some persons to make, as we find not a few people who take pride in boasting that they have arrived at middle age and still enjoy an undiminished acuteness of vision. Such persons imagine, and they easily persuade themselves that their imagination is the truth, that their constitution is so robust and their bodily vigor so great that the ordinary senile changes that affect others' eyes cannot touch them; but they are finally brought face to face with the fact that they must have been mistaken, and that, after all, their eyes are not very much better than ordinary eyes. They only acknowledge themselves beaten when actually compelled to do so, because of their inability to any longer read, write, or do fine work with their unassisted eyes.

This disposition to deny the existence, or at least the commencement, of aged sight is further shown by the expressions used by the patient in describing his experience. He will remark that "My eyes were always good until recently, and I think I must have strained them, or, perhaps, I caught cold in them; at any rate, I think they will be all right again in a few days." Another one will say his sight has been impaired by night work or overwork. The next patient may say that his "sight was always excellent, and never began to fail until within the past few months," or, that "the print which he was always accustomed to read now begins to blur and look dim." While these excuses in some cases may be made in ignorance, yet, in the majority of cases, we are led to believe they are made with a desire to conceal the real cause, and to avoid lending color to the fact that one is getting old enough to develop presbyopic symptoms.

This interference with the clearness of reading and writing and all close use of the eyes, which commences so gradually and insidiously, as described above, rapidly and steadily increases, and in the course of five or ten years distant vision also becomes slightly impaired, that is, the sharpness of sight which the individual enjoyed in his earlier life becomes somewhat dulled. This impairment of distant vision, however, may not be so great as to cause any inconvenience; in fact, it may be so slight, and vision for distance remain so good, as to escape notice.

If, for any purpose, such a person consults a competent optometrist and undergoes a careful examination of his eyes, the slightly defective vision or the loss of refractive power will be quickly discovered. Or, if by chance he puts on a pair of weak convex glasses (say, for instance, $+ .50$ D. or $+ .75$ D.), he finds everything appears clearer, and the details of the images of distant objects much more distinct, and their outlines a little more sharply defined.

This is a condition of *acquired hypermetropia,* which supplants the natural state emmetropia, the cause of which change of refraction is found in the condition of the crystalline lens, which grows firmer and of more uniform consistency, and, at the same time, becomes flatter. All of these changes tend to diminish the refractive power of the lens, and this causes the focus of parallel rays to fall behind the retina, which is precisely the same condition as occurs in hypermetropia. In the latter case the parallel rays focus behind the retina, because of the shortness or flatness of the eyeball, while in presbyopia the focus falls behind the retina on account of the flatness of the lens. The result is the same in each case—the impairment of distant vision and its correction calls equally, in both cases, for a convex lens.

In hypermetropia the symptoms indicating the approach of presbyopia appear at a very much earlier period of life, and in such cases it is usually accompanied with evidences of muscular fatigue and nervous and vascular irritation.

In myopia, on the other hand, the appearance of presbyopia is delayed, the tardiness of its approach bearing a direct relation to the degree of near-sightedness. So that, in high grades of myopia, it is so much delayed and neutralized that it may never appear. In low degrees of myopia the patient enjoys good reading vision, without the need of glasses, until, perhaps, fifty-five years of age, after which he will begin to need good convex glasses for reading, while he will continue to wear his concave glasses for distance.

In the higher grades of myopia, where the far point lies within a limited distance, presbyopia cannot occur. Presbyopia depends upon a recession of the near point; but the near point can never recede beyond the position of the far point. Now, presbyopia does not commence until the near point has receded beyond eight inches, and hence, if the myopia was so great that the far point was located at eight inches, or nearer, in such cases the near point could never recede far enough away to be classed as presbyopia.

LOSS OF ACCOMMODATION.

The child starts in life with a maximum amount of accommodation equal to about fifteen dioptres, and which does not commence to diminish until the tenth year of life. This is the earliest age at which accurate observations can be made; but the probabilities are that the infant possesses a still greater amount of accommodative power, perhaps equal to twenty dioptres, or even more. At forty years of age this has diminished to five dioptres, or less; at forty-five years, to three dioptres; and at sixty-five or seventy years, scarcely one dioptre of accommodative power remains.

Of the fifteen dioptres of accommodation which the child of ten years is able to bring into action by the strongest effort of his volition, a considerable proportion (from two-thirds to three-fourths) may be lost before much inconvenience results in ordinary near vision.

In emmetropia the distance of the binocular near point represents the number of dioptres of accommodation; hence, a near point of eight inches represents five dioptres of accommodation, and, with the exercise of this amount of accommodation, the smallest print in ordinary use can be easily deciphered by eyes of average visual acuteness at the said distance of eight inches. When the power of accommodation is reduced to four dioptres, ordinary newspaper print can then be easily read at a distance of ten inches.

With the loss of another dioptre of accommodation, that is, when three dioptres only are available for use, the near point has receded to thirteen inches, and now the reading of fine print becomes somewhat difficult, except under the most favorable conditions of good illumination and normal acuteness of vision. The patient has now reached the age of forty-five; and very few persons attain this age without being made conscious of some defect in vision, and without seeking help from convex glasses in reading or other fine work. When an emmetrope does begin to wear glasses, under forty years of age, it is generally due either to the exacting nature of the work in which he habitually employs his eyes or to the fact that his acuteness of vision is somewhat below the normal.

When the patient has reached the age of fifty or fifty-five, and the power of accommodation has diminished to two dioptres and the near point has receded to twenty inches, the book must now be held at arm's length, which is such an inconvenient distance as to practically prohibit all use of the eyes for close work, except in the case of very unusually large print; although, even with this range of accommodation, a public speaker may be able to read fluently from a plainly written manuscript lying before him upon a reading-desk or table.

The muscle of accommodation, as is the case with any muscle or organ of the body, loses tone and strength if not called into action to perform its usual function for any considerable length of time. Therefore, in cases of protracted and exhausting illness where the patient is unable to use his eyes during all that time, and the muscle of accommodation necessarily falls into a condition of inactivity, there may be a premature development of presbyopic symptoms, which, as a matter of course, are interpreted as an indication for the immediate adoption of convex glasses.

Another factor must be considered as tending toward the same result. These symptoms are due, not only to the total disuse of the accommodation during the illness, but also to the fact that the muscle of accommodation participates in the general bodily weakness occurring at that time. The impairment of vision varies very much in different individuals, in some cases causing but slight interference with the ordinary use of the eyes, while in other cases it is so pronounced as to prevent all use of the eyes for close work, unless some assistance is given in the shape of convex glasses.

In such cases the glasses prescribed should not be too strong.

but should be of the least power compatible with the use of the eyes under favorable conditions of illumination. The reason why preference should be given to the weaker glasses is that the ciliary muscle should not be relieved of all incentive to action. The stronger the convex glass prescribed, the less the need of any exercise of accommodation. The weaker the convex glass prescribed, the greater the need of action of the accommodation. In other words, the convex lens, to the extent of its power, relieves the ciliary muscle of the exercise of its functions in the same degree.

Now, in these cases, if the ciliary muscle was relieved of all necessity for action, it would remain in the same condition of disuse, and would, therefore, be placed under the most unfavorable conditions for regaining its lost strength. Whereas, if it was encouraged to act, and if it was called upon to perform only so much work as it could comfortably perform, such a method of management would tend to develop its powers, and would place it in a position the most favorable for regaining its original tone. Therefore, the patient should be encouraged in the hope that the eyes will soon grow strong again, and that, as the accommodative power increases with use, the glasses may soon be laid aside.

Sometimes, in cases of this kind, it is possible to dispense with the aid of glasses, and in their place, and as a substitute, to use a solution of pilocarpine, and thus postpone the use of glasses for, perhaps, several years. The action of pilocarpine (which is the active principle of jaborandi) is to contract the pupil and stimulate the ciliary muscle, and its use twice daily for several weeks is very effective in again bringing the accommodation into use.

The diminution of the range of accommodation and the recession of the near point which accompanies advancing years is a strictly physiological change, and must not be considered as in any sense an unnatural condition, dependent, as it is, on the steady increase in the hardness of the crystalline lens, in consequence of which it becomes less and less capable of undergoing the necessary change in shape or increase in curvature which is required for the adjustment of the eye for near vision.

As this increase in the density of the lens substance occurs in all eyes alike, irrespective of their condition of refraction, and as there are no exceptions to this change, it would seem entirely proper to define presbyopia as the loss of accommodative power incident to advancing years. Usage from time immemorial and popular feeling on the subject, among optometrists as well as the laity, have, however, associated the name with the special condition in which, as a result of increasing years, near vision becomes impaired, distant vision remains unaffected.

Viewing the subject in this light, presbyopia may be said to be an incident in the life history of every individual who reaches and passes middle life, with but few exceptions. The only exceptions are in cases of myopia, and then only when the myopia exceeds 4 D., because, in such eyes, the near point can never recede beyond ten inches, which is within the usual reading distance for fine print. Hence, the recession of the near point to an inconvenient distance, or the failure of vision for small objects close at hand, which are the characteristic and distinguishing marks of prebyopia, can never occur.

Myopia and presbyopia in many ways seem directly antagonistic. In myopia only near objects are seen clearly, while distant vision is very indistinct; and in presbyopia distant objects are seen clearly, while near vision is very indistinct. This apparent antagonism was recognized very early in the history of mankind, and because the nature and causes of the two conditions were not properly understood, myopia was regarded as the exact reverse of presbyopia for more than two thousand years.

With our present knowledge on these subjects we are now aware that it is hypermetropia, and not presbyopia, that is the true opposite of myopia; but hypermetropia and presbyopia remained confounded until the middle of the present century, when the demonstration of the change in the form of the crystalline lens in accommodation by Cramer and Helmholtz, and the masterly analysis of the phenomena of accommodation in its relation to the several anomalies of refraction by Donders, dispelled the cloud of obscurity in which the whole subject had been so long developed, and through which only momentary glimpses of the truth had been previously enjoyed by a few exceptionally acute observers.

PRESBYOPIA AS IT AFFECTS HYPERMETROPES AND MYOPES.

A hypermetrope and a myope who had their defects properly corrected and wore their glasses constantly, would begin to experience the disabilities of presbyopic vision at about the same age, and in nearly the same degree, as an emmetrope. About the age of forty, or soon thereafter, the hypermetrope discovers that his convex glasses are no longer quite sufficient for reading, and at the same time the myope finds that his concave glasses are becoming something of a hindrance in near vision, although, in both cases, the correcting glasses (in the first person convex and in the second concave) still continue to answer perfectly well for distance. A change to stronger convex glasses by the hypermetrope, or, rather, to an additional pair of spectacles fitted with stronger lenses, and to weaker concave glasses by the myope, or, perhaps, even to a temporary removal of his glasses, are the remedies which now suggest themselves and which, sooner or later, must be adopted.

With these changes in the glasses near vision again becomes easy, but these reading glasses produce a corresponding diminution in the distinctness of distant vision. Consequently, in order that the individual may enjoy clear vision both for reading and distance, it becomes necessary to prescribe for the middle-aged ametrope two pairs of glasses, the one pair to correct the error of refraction and to be worn for distance, the other pair to be modified by the requirements of the accommodation and to be used for reading, which calls for stronger convex in hypemetropia and weaker concave in myopia.

A hypermetrope who does not wear any glasses to correct his defect will experience the disabilities of presbyopia at a much earlier age than an emmetrope, after having passed through a more or less protracted stage of suffering from asthenopic symptoms. In myopia, on the other hand, if of not too high a degree, the defect may remain uncorrected without any impairment of reading vision, but with the advantage of retaining the reading power with the unaided eye until a more advanced age than in emmetropia. In the higher grades of myopia the reading power is not impaired by the advance of years, but it is retained indefinitely.

THE BINOCULAR NEAR POINT.

The crystalline lens of the youth, on account of its softness and elasticity, is easily changed in shape by but a slight effort of accommodation. The increasing firmness of the lens of the adult who has arrived at middle age presents a much greater resistance to be overcome in order to effect as much the desired degree of accommodative adjustment as is still possible in presbyopia, and, therefore, calls for a relatively much greater effort of accommodation.

In other words, the effort of accommodation required to adjust the eyes for a certain near point (say twelve inches) is much greater in middle age than in youth, while the effort of convergence is about the same in both cases. This disturbs and changes very materially the natural relation existing between the functions of accommodation and convergence; and the binocular effort of accommodation which is associated with convergence for the accustomed reading distance of from thirteen to fifteen inches finally represents nearly the total effort of accommodation which it is possible for the eye to exert by the strongest action of its will. That is, the binocular near point, as thus found, in reading, coincides very nearly with the absolute near point.

When convex glasses begin to be used for reading, as is required in presbyopia, the distance of the near point increases very rapidly, and it is found that such reading power as may have been retained up to the time of the commencement of the wearing glasses is speedily lost, and then reading without glasses becomes almost, or entirely, impossible. Hence the usual experience of presbyopes is that, having once formed the habit of wearing convex glasses, their continued use has become imperative, and this is generally the case whether the person has commenced to wear the glasses rather earlier than absolutely necessary, or only after the need of them has been most urgently felt.

It would, therefore, seem as if the too early use of convex glasses in presbyopia was rather to be avoided, as entailing upon the wearer all the disabilities of presbyopia several years, perhaps, before they are normally due, and this is an argument that is often used by persons who, for various reasons, wish to defer the wearing of glasses as long as possible.

But there are two sides to every story, and, in our opinion, the persons who are guided by the above reasoning as to the time when it is proper to begin to wear glasses are in error, and sooner or later they are made aware of it by the injury done to their eyes. The appearance of presbyopia is a physiological process.

and the wearing of glasses for its correction is nothing more than supplying one of the natural needs of the system, and it is, therefore, the height of folly and presumption for weak man to attempt to thwart one of the inevitable laws of Nature; hence, the proper method of treatment is to recognize presbyopia early and to supply optical help liberally.

A man of vigorous bodily constitution, with a correspondingly strong muscle of accommodation, may be able to defer the wearing of glasses for several years after the first symptoms of presbyopia begin to manifest themselves; but his ability to do this is accomplished only at the expense of a great strain upon his accommodation, which, perforce, in time weakens and destroys its integrity.

If the glasses are worn quite early the strain is removed from the accommodation, and they supply the necessary convexity for focusing the rays upon the retina which aforetime was furnished by the ciliary muscle, and in proportion as this muscle is relieved of the necessity for extra exertion, in the same ratio does it lose its power to accomplish this act when deprived of the assistance on which it has been depending.

THE RELATIVE STRENGTH OF ACCOMMODATION AND CONVERGENCE.

In studying the functions of accommodation and convergence, and their relation to each other, and the effect of age upon them, one cannot help but be struck by the fact that accommodation begins to fail at the tenth year of life, and at the age of forty-five the impairment of its function has become so marked as to interfere with the use of the eyes in the ordinary occupations of life; while convergence and the vigor of the muscles that control it (internal recti) continue unimpaired by the flight of years.

The statement has been made on these pages, and is again repeated, that the functions of accommodation and convergence bear a distinct relation to each other, and, under normal conditions, are brought into exercise in the same proportion. For every effort of accommodation there is a corresponding employment of convergence, and for every effort of convergence there is a corresponding employment of accommodation.

This correlation naturally existing between accommodation and convergence is disturbed by the several errors of refraction.

and, also, by the senile changes that sooner or later overtake the eyes of every individual. In hypermetropia an excessive effort of accommodation is required to overcome the defect, in which class of cases the accommodation is in excess of the convergence. In myopia, on the other hand, but little effort of accommodation is required, while the nearness at which the object is necessarily held calls for a decided effort of convergence, and, in such cases, the convergence is in excess of the accommodation. This may lead on to the production of asthenopia, in the first case being accommodative, and due to exhaustion of the ciliary muscle; in the second case being muscular, and due to insufficiency of the internal recti muscles.

In presbyopia there is found a like disturbance of the smoothness with which these two functions act in conjunction, but the mechanism of the change is a little different. In these cases the disparity is due, not to the necessity for the exercise of one function in excess of the other, but to the actual weakening of the muscle of accommodation, in the first place, and to the increase in the density of the crystalline lens, which becomes less and less able to respond to the contractions of the muscle, in the second place. Instead, then, of one function being in excess of the other, there is a deficiency of the accommodation as compared with the convergence.

PRESBYOPIA AND HYPERMETROPIA.

Presbyopia is essentially an error of accommodation, and hypermetropia is essentially an error of refraction. This is the distinguishing difference between the two defects, which are so apt to be confounded on account of the similarity of their symptoms and on account of the same spherical convex lens being used to correct them both.

The student should keep clearly in mind the distinctive difference between presbyopia and hypermetropia, as the inexperienced optometrist is sometimes confused by the fact that the former sometimes apparently develops into the latter. This is not actually the case; but, as has been already explained in this chapter, in addition to the impairment of accommodation, which is the essential characteristic of presbyopia, the senile changes occurring in the eye all tend to a diminution of its positive refracting power, so that, finally, an emmetrope becomes slightly hypermetropic (a condition of acquired hypermetropia), a hypermetrope becomes still more hypermetropic, and a myope somewhat less myopic.

This gives rise to the popular notion which is so prevalent, that a person who is myopic in youth loses his defect of sight as he approaches middle age, and regains his normal vision. This is only partially true; the fact is, that while myopia is partially neutralized by the natural diminution of refractive power, it is only the very slight degrees of myopia that pass over to emmetropia.

A small degree of hypermetropia, which sooner or later necessarily becomes absolute, is, in fact, the ultimate normal condition of all emmetropes, so that the time finally arrives when weak convex glasses will be required by such persons to clear up their distant vision; at such a time, and for similar reasons, the hypermetrope will require an increase in the strength of his convex glasses, while the myope will retain the same acuteness of distant vision with a weaker concave glass.

This diminution in the refraction of the eye scarcely begins to be noticed at the age of forty-five, when the symptoms of presbyopia first begin to make their appearance. Even at sixty years of age it scarcely amounts to half a dioptre, and it is not until the person reaches the allotted three score years and ten, or over, that a + 1 D. lens is required to neutralize the acquired hypermetropia.

LOSS OF ACCOMMODATION IN PRESBYOPIA.

The deficiency of the power of accommodation depends on the age of the individual and the degree of prebyopia present in each particular case. In the early stages of presbyopia, before the strength of accommodation has become markedly impaired, a weak convex lens only is required in the way of assistance, as the remaining accommodation is sufficient to complete the focusing of the rays of light upon the retina.

The older the patient and the higher the degree of presbyopia present, the greater the deficiency of accommodation, until finally it is lost altogether, and then the power of the correcting convex lens must be increased until its principal focus will coincide with the distance of the reading point from the eye, and the focusing of the rays on the retina is accomplished entirely by the spherical convex lens, and without any assistance from the accommodation.

In the different degrees of presbyopia there is a great variation between the amount of focusing that shall be done by the glasses and that which shall be accomplished by the effort of accommodation; and the fixing and determining how much shall be done by the lenses prescribed, and how much shall be left to the accommodation, opens up a wide field in the optical therapeutics of presbyopia for the exercise of the judgment of the optometrist and to test his skill.

As has already been explained at considerable length, the near point represents the full power of accommodation which the patient is able to bring into play by the strongest effort of his volition, but this maximum of exertion of which the ciliary muscle is capable could not be sustained for any length of time for reading or sewing, or any other near work. The portion of the focusing that should be left for the accommodation to do must, therefore, be considerably less than the total amount of the accommodation power.

It has been found that young persons under thirty years of age cannot employ more than half their total power of accommodation for any continuous use without suffering from eyestrain and symptoms of asthenopia. But those who are older, and whose accommodation is, on that account, greatly diminished, are able to use two-thirds of what remains without inconvenience. These proportions are only average, and although given to us by high optical authorities, they cannot be considered as inflexible; in fact, the optometrist, in his daily work, finds so many individual cases that vary widely from these figures and proportions that he is tempted to doubt the truth of them. However, in prescribing a lens for the correction of presbyopia, in the absence of other indications he would be safe in following the rule to select a lens of such strength as would allow the patient to use two-thirds of his remaining accommodation for near work.

The time of life at which presbyopia will occur in emmetropic eyes is determined by the progress of the failure of accommodation, and the nearness of the point at which it is required to see clearly. The watchmaker and engraver are compelled to bring their work very close to their eyes in order to see the fine details of it, and are, therefore, oftentimes compelled to use a convex lens before the age of twenty. The laborer and the farmer, on the other hand, whose occupations are such as not to require any very close use of the eyes, frequently pass the age of fifty before the inconveniences of presbyopia are noticed.

These are examples of the two extremes; in the other instance demonstrating in a certain class of cases the early need of glasses, and in the other illustrating the age some persons may reach before the need of glasses is felt. For the mass of people, however, there is a daily necessity for more or less use of the eyes in near work, as in reading, writing and sewing, which is done in different cases at distances varying from twelve to eighteen inches; and, hence, very few people are able to pass the age of forty-five without seeking occasional help from glasses, or, at least, without feeling the need of such help. And for similar reasons, in emmetropic eyes, it is very rare for the disabilities of presbyopia to make their appearance until after the age of forty.

APPEARANCE OF PRESBYOPIA.

The word presbyopia, therefore, is used to express a condition which depends on its approximation to, or departure from, a certain standard, which is arbitrarily fixed at different points by different authorities. In our judgment, the point of departure should be fixed at eight inches, and in accordance with this standard we have defined presbyopia in these pages as that condition of the eye in which the near point has receded beyond this limit of eight inches, and, as a consequence, the person has difficulty in using the eyes for close vision.

On account of the difference in the ages of different persons when presbyopia makes its appearance, and because it does not correspond to some well-defined condition, as do the terms myopia, hypermetropia and astigmatism, Landolt seems very much dissatisfied with the word, as evidenced by the following extract taken from his manual of "Examination of the Eyes": "But I frankly acknowledge that, in my opinion, it would be best to drop the term entirely out of our nomenclature, and to determine simply what lenses the patient has need of, not to see at a certain specified distance, but at the distance at which he is accustomed to use his eyes, or at which his work compels him to see. This can be done by taking account of his refraction and accommodation, as will be explained further on."

Although Professor Landolt is an eminent scientist and distinguished ophthalmologist, and his opinion is at all times, therefore, to be respected, yet we cannot give his views as above without, at the same time, entering a vigorous protest against their adoption. We cannot see that he presents any convincing arguments why the term presbyopia should be dropped, and especially as he does not offer any other term as a substitute for it. In following out his views we would be deprived of the use of any term or word to describe that group of symptoms which are familiar to optometrists everywhere as belonging to the condition we know as presbyopia, which, if it does not express a definite and well-cut condition, at least presents to our mind a certain condition of the accommodation and a corresponding failure of near vision, which is measured in a certain way and corrected by a certain kind of lens.

Landolt's idea, as described above, is to determine simply what lenses the patient has need of, and he would, therefore, add to the definition of presbyopia as we have given it, or, rather, he would change it as follows. "Presbyopia finds its expression in the number of positive dioptres which it is necessary to add to the eye in order to procure a positive refracting power of 4.50 D."

It will be seen that this has reference to a near point of 22 centimeters, or nine inches, instead of eight inches, as we prefer to make it. In order to see at this latter distance, there is evidently a positive refracting power required equal to 5 D. We have, on a former page, given a table representing the amplitude of accommodation possessed by the eyes at different periods of life; a reference to which will show the student the surplus of accommodation possessed in youth, which gradually lessens until middle age shows it has passed over to a deficiency.

Early in life, when the eye enjoys a great reserve of accommodative power, there is no difficulty in seeing at eight inches, and with a surplus of accommodative power left over. As age advances, and the accommodation diminishes, there is less and less surplus left over, and, finally, the time arrives when all the refractive power is required to adjust the eye for vision at eight inches, and there is no surplus of accommodation in reverse.

A little later on, and we find that the eye no longer possesses a refractive power of 5 D., nor the ability, by any effort of its own, to see at the near point of eight inches, and then it evidently becomes necessary to increase the refractive power by means of a convex lens of such power as will make it equal to 5 D. This lens, then, will measure the degree of the presbyopia

ANOTHER DEFINITION OF PRESBYOPIA.

According to the line of reasoning just described, we can formulate a definition of presbyopia to be enunciated something like this: Presbyopia finds its expression in the number of the lens that represents the amount of the positive refracting power which it is necessary to add to the dioptric system of the eye in order to obtain a total positive refracting power equal to 5 D., which represents a near point of 20 centimeters, or eight inches. Or, in other words, the amount of presbyopia is expressed by that strength of convex lens which it is necessary to place before the eye in order to bring the receded near point back to eight inches.

A study of the table and the diagram given on this and the following page will show the reader that, at the age of forty years, the emmetropic eye is scarcely able to exert a positive refracting power of 5 D., and its near point is beginning to recede beyond eight inches. From this time on the eye begins to be presbyopic.

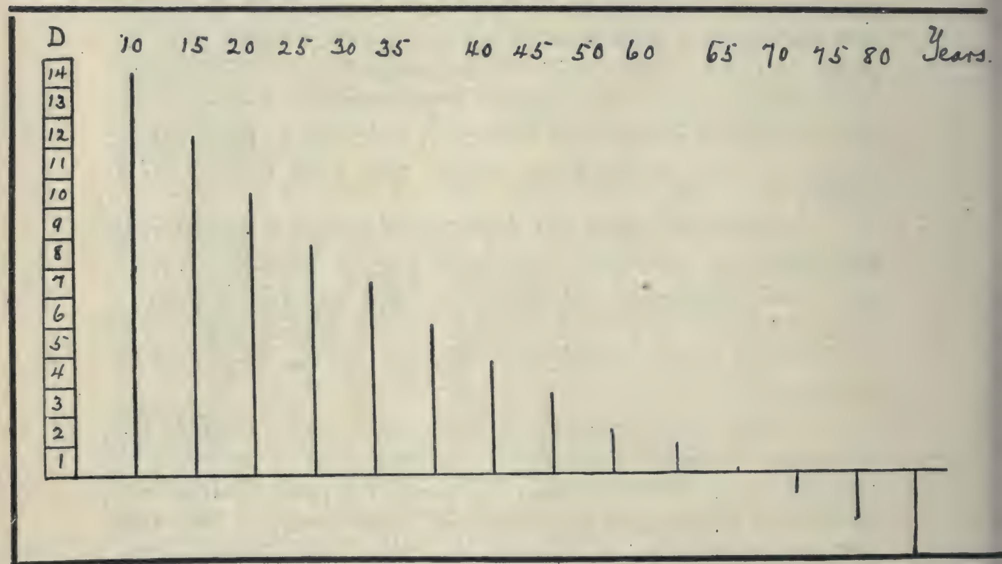
The degree of presbyopia in emmetropic eyes is equal to the difference between its positive refracting power, expressed in dioptres, and 5 D., which latter represents the point of departure for the commencement of presbyopia. The result of this sum of subtraction designates, at the same time, the number of the lens which the emmetropic eye requires for the correction of its presbyopia.

By making use of this rule, the following table is obtained, always remembering that it refers to the presbyopia of emmetropic eyes:

Age.	Positive refractive power.	Degree of presbyopia.
40	4.50 D.	5 D. — 4.50 D. = .50 D.
45	3.50 D.	5 D. — 3.50 D. = 1.50 D.
50	2.50 D.	5 D. — 2.50 D. = 2.50 D.
55	1.50 D.	5 D. — 1.50 D. = 3.50 D.
60	.50 D.	5 D. — .50 D. = 4.50 D.
65	0	5 D. — 0 5 D.

Table compiled to show the degree of presbyopia at different ages, as ascertained by subtracting the positive refractive power at each age from 5 D.

The positive refracting power of the eye gradually diminishes with each year of life; but there are no evidences of this diminution of refractive power apparent during youth or early manhood, and not until after the fortieth year of life, when its deficiency must be supplemented by a convex lens, placed before the eye. From this time on, the loss of refractive power is marked and rapid, until the sixty-fifth year of life, when it is entirely lost, and then passes over to the negative side. As the refracting power of the eye, at this time, is no longer a positive



This diagram represents the amount of refractive power at different ages by the height of the upright lines, illustrating the gradual diminution from 10 years to sixty-five years, and then passing over to the negative side. The figures on the left indicate the number of dioptres of accommodative power, and the horizontal line of figures the different ages.

force, but is now a negative quantity, for this reason it becomes necessary to add its value to the usual 5 D., in order to obtain the degree of presbyopia, instead of subtracting it, as in the years prior to this.

It should be noted that the commencement of presbyopia is not deferred until the positive refracting power of the eye has been entirely lost, as at first sight might seem to be the case. Presbyopia does *not* commence where the refracting power stops. The 0 of the positive refracting power of the eye is not reached until the emmetrope is sixty-five years of age, whereas presbyopia, from being nothing at the age of forty years, begins to develop at this time, and increases at the rate of one dioptre for every five years, from forty up to sixty years of age. There is a break, at this time, in the regularity of its increase, there being an advance of only .50 D. from sixty to sixty-five years of age, after which the same ratio of increase again holds good, that is, one dioptre for every five years, until the emmetrope has reached the patriarchal age of eighty years.

AMOUNT OF AVAILABLE ACCOMMODATION.

In studying a table that is given on page 379, it will be seen that the measure of the presbyopia is determined by that lens which it is found necessary to add to the positive refracting power of the eye, in order to raise it to 5 D. In other words, the eye must be able to possess this amount of accommodative effort, either naturally or artificially supplied. Now, with this amount of positive refracting power possessed by the eye, the question occus: What proportion of it is available for continuous use?

One thing is certain, and that is, no eye is capable of calling into action the total amount of its positive refractive power and keeping up this exertion for any length of time. Therefore, only a certain proportion of the total amount of accommodative power is available for use in the ordinary occupations of life that call for near vision, and, while that proportion will vary greatly in individual cases, we may, perhaps, strike a general average, which will serve as a basis for our studies, and assist us in the proper understanding of this subject.

Following out this matter along these lines, we have prepared the table on page 379, which shows the average diminution of the positive refracting power for each five years, the amount of available accommodation for habitual work, and the strength of the lens that would be required to supplement this accommodation to permit of continuous near work at the usual reading distance, always presuming that we are figuring on an eye supposed to be emmetropic.

It has always been customary to teach optical students that a patient is able to comfortably use, for continuous near work, only one-half of the total amount of the accommodative power he possesses. This is more likely to be the case with young persons, but it is not an unsafe rule to follow at all ages. However, during the presbyopic period of life, when the amount of available accommodation is very considerably diminished, it is often found that perhaps two-thirds of what remains can be brought into continuous use without any perceptible inconvenience.

The reading distance is usually considered to be at twelve to thirteen inches for the average number of persons; tall people may hold their book farther away, while short persons may find it more convenient to hold it closer. This distance may also be varied according to the calling of the individual; in those occupations which require very close vision, the habit is formed of holding the book near the eyes. In those occupations, on the other hand, where the work is placed at arm's length, or farther, the person oftentimes falls into the habit of holding his reading matter no closer than fifteen to eighteen inches.

The distance at which the reading is held, or the work is done, is not alone a matter of convenience, or of stature, or of habit, but is directly dependent upon the amount of accommodation possessed by the individual, and available for continuous use.

As an illustration, we will take a man whose total amount of refractive power is 5 D. If this man is emmetropic, his age is about forty years, and he is just beginning to be presbyopic. This individual's near point is at eight inches, at which distance he is able to see only by the exercise of all of his refractive power. Vision, at this point, is possible for only a few seconds or the fractional part of a minute.

For sustained vision, such a person cannot use all of his positive refracting power, and, therefore, cannot see at eight inches; but he can use only a certain proportion of this 5 D., which will throw his reading distance further away. If he uses only one-half of his refractive power, that is, 2.50 D., his reading distance will be sixteen inches. If he is able to use two-thirds of it, that is, if his available accommodation is 3.34 D., his comfortable reading point would be as close as twelve inches.

Hence, the proper reading distance for such a person would depend on two factors: First, the total amount of refractive power he possessed, and, second, the amount of refractive power that could be considered as available for every-day use. As the majority of presbyopic persons have the ability to use and make available two-thirds of their accommodative power, we have calculated on that proportion in the preparation of the following table:

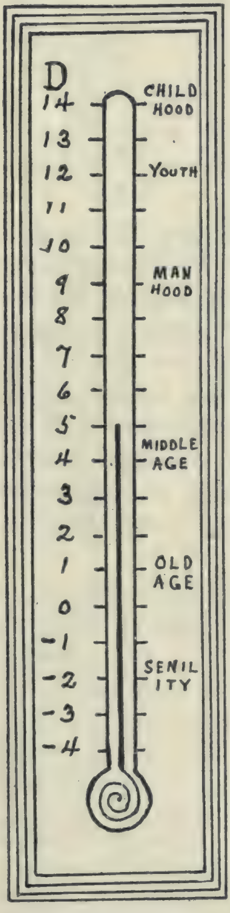
Age.	Dioptres of accommodation.	Dioptres available.	Lenses required.
40	4.50 D.	3 D.	.34 D.
45	3.50 D.	2.34 D.	1 D
50	2.50 D.	1.67 D.	1.67 D.
55	1.50 D.	1 D.	2.34 D.
60	.50 D.	.34 D.	3 D.
65	0	0	3.34 D.

In the consideration of this table, it should be borne in mind that the point of departure for the commencement of presbyopia is when the inherent refractive power of the eye falls below 5 D., and its correction consists in adding a lens of such strength as will restore its refractive power to 5 D. If we consider at this age that two-third of the accommodative power is available for habitual near work, then this 5 D. of total refractive power represents 3.34 D. of working refractive power and this table is based on the principle of supplying a lens of such strength as will keep the amount of available accommodation always at this point of 3.34 D.

The optical student who is just commencing the study of these subjects may, perhaps, be somewhat confused by the lenses .34 D., 1.67 D., 2.34 D. and 3.34 D. He will look over his trial-case very carefully, but he will be unable to find any lenses marked with these numbers. This will be discouraging to him, and apt to make him disgusted with the whole subject. But there is a very simple way out of the difficulty, and that is to substitute that lens found in his trial-case which is next strongest to the one desired.

For instance, in place of + .34 D. we substitute + .50 D.; in place of 1.67 D. we use 1.75 D.; for 2.34 D. we select 2.50 D.; and for 3.34 D., 3.50 D. The difference between these lenses is so slight that this substitution can be made without materially affecting the result; the positive effect of the difference between the lenses, that is, of a lens of + .08 D. and of + .16 D. is so small as to be scarcely appreciable.

In comparing these two tables, it will be seen that there is a very wide variance in the results obtained; but it must be remembered that they are worked out from a different standpoint and on a dissimilar basis. At any rate, we desire to emphasize the statement that these tables are made for the purpose of illustration alone, and they they should not be used as a basis for the prescription of glasses in any individual case.



Accommodative Thermometer.
The figures on the left represent the number of dioptres of refractive power, while on the right are marked the different epochs of life, with the graduations of each from one extreme to the other.

And the point might be emphasized right here that no table has ever been prepared, nor is it within the range of possibility that such a table can be constructed, that should serve as a guide for the selection of glasses in presbyopia. Formerly the idea was prevalent among the people, and it was shared in by jewelers and would-be opticians, that when a middle-aged person felt the need of glasses, all the information that was necessary for the making of a prescription was the age, and immediately the number of the glass would be forthcoming. A table was in use in which the different ages called for a certain number of lens, and the jeweler who possessed such a table considered himself well informed in optics and competent to sell and adjust spectacles. What a pity that such a dream of perfection must be destroyed!

Inasmuch as prebyopia is due to an inability of the power of the accommodation to adjust the eye for things close at hand, it manifests itself by impaired vision, or strain, when the eyes are used upon near objects. Such being the case it is evident that the first indications of it will be noticed when the eye is called upon to look at very small objects, or when the light is poor and dim; or, in other words, when the act of vision is performed under such circumstances as to impose an extra effort, either on the accommodation or on the perceptive layer of the retina, as, for instance, when reading is continued after sunset and when twilight covers the earth, or when it is foolishly attempted by the pale light of the moon, as a thoughtless person is sometimes rash enough to do.

When reading is carried on under such circumstances, the natural impulse of the person is to bring the object looked at closer to the eyes. The reason for this is twofold: In the first place, the near approach of the object yields a larger retinal image, and, in the second place, there results a corresponding increase in the illumination. Now, while the proximity of the object improves vision in the manner indicated, it at the same time imposes an increased effort upon the function of accommodation. This may be possible for a time, but only at the expense of a terrible strain on the eye. Sometimes this extra effort and marked strain may be kept up for an incredibly long time, and all the while the print is clearly seen and near vision seems unimpaired; but, finally, the endurance of the muscle of accommodation is exhausted, and it is no longer able to keep up the strain and maintain the focal adjustment of the eye for near vision, and then it suddenly relaxes, with the result that all distinctness and clearness of near objects are lost, the print blurs and runs together, and reading or sewing has to be discontinued.

A moment's rest, a shutting of the eyes, a pressing of the closed lids with the hands, give the ciliary muscle an opportunity to recover, somewhat, its exhausted strength, and reading again becomes possible for a little while. However, the blurring of the print soon occurs again, and this time after a much shorter interval than before, when the temporary rest and closing of the eyes must again be resorted to before the individual can continue his reading. If, notwithstanding these difficulties in reading, the use of the eyes be persisted in, the intervals of clear vision become shorter and shorter, and the periods of forced rest grow longer and more frequent, until, finally, in spite of all desire to continue, the individual is forced to give up the attempt.

This blurring of the type and difficulty in reading become more noticeable when the general physical condition of the individual has, for any reason, fallen below par, as in cases of recovery from protracted illness, or, in less degree, in the latter part of the afternoon, or in the evening, when the body is wearied and exhausted by the day's exertion.

In cases such as we have been considering, instead of this actual failure of vision and utter inability to continue the use of the eyes, it is remarkable how some persons are able to read fairly well even for long periods of time, although, as a matter of course, it is only at the expense of a great deal of eyestrain. Although conscious of this strain, yet their ability to read is such that they put off the wearing of glasses as long as possible, and, as a result of this neglect, the individual soon begins to complain of irritation or inflammation of the conjunctiva, and the eyes begin to present evidences of vascular congestion.

When such persons catch cold it settles in their eyes, and, as a result, they are afflicted with frequent attacks of acute conjunctivitis, which, after a time, develops into a condition of chronic conjunctivitis, and they are troubled more or less constantly with smarting and burning of the lids, which symptoms are very much aggravated when the eyes are used for near work.

There may be other symptoms of eyestrain sufficiently pronounced to constitute an indication for glasses in presbyopia, but those above mentioned are the ones most frequently met with. Another very common symptom, and sometimes the only one complained of, is that the book has to be held at such an inconveniently great distance in order that the print may be clearly seen.

These various symptoms and evidences of asthenopia are the cry of the eye for help and assistance, and, consequently. the cry will continue as long as such assistance is withheld, and as long as the demand for it exists. Therefore it is not the part of wisdom to disregard this cry, but the careful man should rather anticipate its appearance and endeavor to prevent its occurrence.

This has reference more particularly to the assistance that can be afforded by glasses properly and scientifically adjusted; but it is not always and not only the choice of glasses which is to be determined, but, in some cases, whether the symptoms which suggest the need of glasses may not point to one of those dangerous and insidious diseases of the eye which sometimes make their appearance as middle life is reached.

One of the most common of the morbid changes which come on at this age, and threaten the eye with a total loss of vision, is that dreadful disease *glaucoma*, which so often manifests itself to the patient and his friends (and, sorry to relate, sometimes even to the optometrist) for a considerable length of time solely by the one symptom of a rapid increase of what is considered "old sight."

GLAUCOMA.

Glaucoma is a disease characterized by an abnormally increased intra-ocular pressure, and under this heading there is associated a group of symptoms which are to be referred in large part to this increased tension. Unfortunately, the symptoms complained of are not always directly and distinctly suggestive of the disease, and, therefore, it is often overlooked in its incipiency.

The patient complains of his vision becoming gradually impaired, and of nothing more, as a rule. This manifests itself by a steady and gradual recedence of the near point, and an early appearance and a marked increase of presbyopia. This is due to, and dependent on, a pressure on the ciliary muscle, which interferes with its action and prevents its contraction, and, therefore, the patient requires a much stronger convex glass for reading than his age would indicate, and there may even be a positive diminution of the refractive power of the eye, simulating a condition of acquired hypermetropia.

In connection with this diminution of the amplitude of accommodation, there is an occasional appearance of colored halos around the flames of lamps and candles, sometimes accompanied with attacks of fogginess of general vision, the duration of which may be but a few minutes, or they may last for several hours. Such attacks of dimness of vision are more apt to occur after a sleepless night or after a meal, and are sometimes accompanied with orbital pains.

It is a well-established fact, and one that is more or less familiar to all optometrists, that the use of mydriatics should be religiously shunned in an eye with a tendency toward glaucoma, as the instillation of a single drop of an atropine solution has been known to develop an attack of this dreadful affliction in a person who has a predisposition to the disease.

An eye with a tendency toward glaucoma has its greatest enemy in a mydriatic, it acting on the eye as a most virulent poison does on the body, and, in fact, no more injury could be inflicted on the eye by stabbing it with a sharp knife than is produced by an acute attack of glaucoma superinduced by the use of a solution of atropine.

For these reasons the optometrist should be extremely careful in ordering atropine to be dropped into an eye for the purpose of examining the condition of its refraction, especially in those persons who have reached or passed the age of forty years. The well-informed optometrist is constantly on his guard not to fall into such an error.

SYMPTOMS OF GLAUCOMA.

In view of the dangerous character of glaucoma, and its liability in the early stages to be confounded with presbyopia, it is a matter of importance to the eye specialist that he should be familiar with the nature and symptoms and appearance of this disease, in order that he may be able to recognize it early, and that such a dangerous disease may not be confounded with the physiological and natural change which we know as presbyopia.

The commencement of the disease, the development of its different symptoms, and the course which glaucoma may run, present numerous variations, and for this reason a precise classification is almost impossible, or, at least, extremely difficult. There are several varities of the disease, but these show a great tendency to pass over into each other. The resemblance of these different forms is quite marked, being distinguished from the very commencement by certain characteristic symptoms, and, although varying somewhat in their course, they all too surely lead to that hopeless condition of blindness in which the eyeball is stony hard, the pupil widely dilated and fixed, the refractive media clouded, the optic disk cupped, and the sight entirely lost.

In studying the different varieties of glaucoma from a clinical point of view, we find that one class of cases is distinguished from the commencement by more or less marked inflammatory symptoms; whilst another class of cases appears to be, to a great extent, free from inflammation. This, naturally, divides the cases of glaucoma into two principal classes, as follows:

1. Cases attended with inflammatory symptoms.

2. Cases in which there are apparently no inflammatory symptoms present.

PREMONITORY STAGE OF GLAUCOMA.

In the great majority of cases of glaucoma there is a premonitory stage of the disease, which is characterized by several or all of the following symptoms. It should be noted that at first these symptoms are only of periodic occurrence and there is usually, in the interval between the attacks, a perfect intermission, or freedom from all trouble. It is in this premonitory, or initial, stage that the optometrist should be able to recognize the disease, not for any purposes of treatment, but solely that the recognition may prevent the catastrophe of dropping a mydriatic into an eye like this, and to distinguish it and differentiate it from presbyopia. In speaking of mydriatics in this connection, we have reference to solutions of atropine, duboisine, and homatropine; cocaine, on the contrary, is a mydriatic which does not increase intra-ocular tension, but, on the contrary, seems to diminish it.

1. *Early Presbyopia or Rapid Increase of Any Pre-existing Presbyopia.* There is recession of the near point and a diminution of the range of accommodation, and also of the positive refracting power of the eye. As the persons attacked by glaucoma are mostly beyond forty-five and fifty years of age, some degree of presbyopia is generally already present; but it is found that this often increases in a very rapid and marked manner during the premonitory stage of glaucoma, so that the patient may be obliged, in the course of a few months, frequently to change his reading-glasses for stronger and stronger ones.

This rapid increase in the presbyopia appears to be due, not so much to a flattening of the cornea through an increase in the intra-ocular tension, as to the action of this pressure upon the nerve supplying the ciliary muscle, thus causing paralysis of the latter. Some authorities have called particular attention to the fact that hypermetropia very frequently occurs together with glaucoma. It seems probable that hypermetropic eyes are more prone to glaucoma than others; and, again, hypermetropia may be developed in the course of the disease. The cause of this is somewhat obscure, but the most probable explanation is that it is dependent upon changes in the crystalline lens, by which its refractive power is very considerably diminished.

In view of the fact that the majority of the eyes that are predisposed to glaucoma are either hypermetropic or astigmatic, or both, it naturally follows that the full correction of the ametropia should be made and that the glasses should be worn constantly. The eye should never be subjected to any strain, and should be used as little as possible by artificial light, and care should also be taken to avoid all strong emotional excitement, because there is certainly a large nervous element in the causation of this disease.

2. *Increased Tension of the Eyeball.* The method of ascertaining the degree of intra-ocular tension is as follows: The patient is directed to look slightly downward and to gently (not tightly) close the lids. The optometrist then applies both his forefingers to the upper part of the eyeball behind the region of the cornea, that is, over the sclera. The pressure should not be applied directly to the cornea, as this seems to increase the tension.

One forefinger is pressed slightly against the eye so as to steady it, whilst the other presses gently on the ball from the opposite side, and in this manner estimates the degree of tension. by ascertaining if it is soft and yielding, or hard and unyielding.

It is important that the optometrist should make himself thoroughly acquainted with the normal degree of tension, which experience he can gain by the examination of a large number of healthy eyes. In this way the tips of his fingers become familiar with the normal degree of tension, and he is thus the more readily able to detect any departure from this condition. If, in spite of this education of the tips of his finger, the optometrist should still be in doubt as to whether there is any increase of the degree of tension in any particular case he can compare it with the patient's other eye, if healthy, or with some other healthy eyes, and by this comparison he will be able to determine the increase of tension, if any exists. This is usually a simple matter and presents no difficulties, except in cases of œdema of the eyelids or chemosis of the conjunctiva.

In place of the fingers, instruments have been devised to estimate the degree of intra-ocular tension with the extremest nicety possible. These instruments are called *tonometers*, but it must be admitted that the results obtained by their use are not sufficiently accurate to render them preferable to palpation by the fingers. Various forms of tonometers have been invented by different authorities, some of which have appeared to answer better than others. One of them is constructed on the principle of indicating the depth to which a minute pin connected with the instrument is pressed into the sclerotic, and also the force employed to produce the depression. A modification of this tonometer was afterward introduced, with which an impression or depression is made in the sclerotic with a given definite force, the depth and breadth and general shape of which can be accurately measured in all directions.

It seems to us not only useless, but preposterous, to make these attempts to devise an instrument to perform something which is so easily and so much better accomplished by the fingers. In this instance, as in so many other cases, Nature affords us a better instrument than art can supply, yet discontented man tries to improve upon it.

NOMENCLATURE OF TENSION DEGREES.

Signs have been devised designating the different degrees of tension of the eyeball which will be found of some use, not only in practice, but also in making and keeping an accurate record of the state of the tension of any particular eye and its variations, from time to time, as well as the advantages of such a system in the reporting of a case.

Gentlemen who have given attention to this subject have found it possible and useful to distinguish nine degrees of tension of the globe of the eye, which, for convenience and accuracy in recording cases, have been designated by special signs.

"T" stands for tension and "Tn" for normal tension. The interrogation point (?) is used after a sign to indicate that there is some question or doubt as to whether the sign accurately expresses the condition of the tension, and, in many cases, this is as near definite as it is possible to describe it.

The minus (—) and plus (+) signs preceding the letter T. are used to designate whether there is a diminution or increase of the natural tension, while the numerals following the letter T indicate the degree of diminution or increase.

TENSION SIGNS.

Tn. Tension normal.

+ *T. ?.* A very slight possible increase of tension, with a large element of doubt as to whether there really is an increase or not.

+ *T. 1.* First degree of increase of tension, slight but without any doubt.

+ *T. 2.* Second degree of increase of tension. Tension is considerably increased, so that the fingers can make but a slight impression upon the coats.

+ *T. 3.* Third degree of increase of tension. Extreme degree of increased tension, the eyeball is of stony hardness, so that the fingers cannot dimple it by the firmest pressure.

— *T. ?.* Indicates a slight possibility that the tension is below normal, with very much doubt as to whether there really is any diminution of the natural tension.

— *T. 1.* First degree of diminished tension, the diminution being slight but undoubted.

— *T. 2.* Second degree of reduced tension. Tension is so markedly diminished that the eyeball feels soft to the touch.

— *T. 3.* Extreme degree of diminished tension. The ball of the eye is so soft and flabby as to allow the finger easily to sink into its coats.

It might seem, for ordinary purposes, as if some of these signs were carried to the extremes of refinement; and so they are, for the optometrist. But for the oculist who desires to make an accurate record of his cases, in studying the nature and watching the course of various disease of the eyeball, that are under treatment, there must be some method of distinguishing the tension, and these signs have as much precision as is, perhaps, attainable under the circumstances.

At the same time, it must be understood that the application of these symbols to the various degrees of tension, and their interpretation, depends very much on the observer, and varies greatly with different persons, because the impression of resistance ascertained by the fingers does not convey exactly the same idea to every observer's mind. For instance, if a certain case of increased tension be examined by two different optometrists separately and apart from each other, one may record it, + T. 1, and the other write it + T. 2. Or, the same case of reduced tension may be recorded by two different observers as, — T. ?, and — T. 1. Such being the case, a certain sign does not always represent a definite degree of increased or diminished tension.

It should also be borne in mind that the normal tension has a certain range or variety in persons of different age, build or temperament; and, also, according to varying temporary states of the system as regards fulness and depletion. A little experience makes the optometrist familiar with these variations, which can then be scarcely confounded with the abnormal grades mentioned above.

THE SIGNIFICANCE OF INCREASED TENSION.

Increased intra-ocular tension, then, is the chief and essential symptom of glaucoma, in whatever stages or form the disease may present itself to the optometrist, although this increase of tension may not be present in the same degree at all times.

In making an examination of the tension of a normal eyeball according to the method described above, the optometrist will find that the eyeball dimples slightly on pressure, and that a sensation of fluctuation is communicated to the fingers, such as is caused by a collection of fluid contained in a tight, hard capsule. The amount of this pitting or fluctuation varies according to the degree to which the eyeball is filled with its humors, and, also, to some extent, according to the thickness of the sclerotic coat; and therefore, as stated above, it is not precisely the same in every eye, even though normal.

In the premonitory stages of glaucoma, the tension of the eyeball, though markedly increased, does not reach a very high degree. In families in which glaucoma is herditary, a marked increase of tension is often met with even in early life, although the disease may not break out till a much later period of life, or even not at all.

In such cases it is proper to regard this increase of tension as abnormal and as a predisposing element of glaucoma, more particularly if it be accompanied with hypermetropia and a diminution of the range of accommodation out of proportion to the defect.

It has been supposed by some authorities that the increased degree of tension always precedes, for a longer or shorter period, the other symptoms of glaucoma; but other eminent authorities have met with very marked exceptions to this rule. Still, an increase in the tension of an eyeball should always excite the suspicions of the optometrist, and should at once lead him to examine the eyes as to whether any other symptoms of glaucoma are present. Even if none are found, still the eyes should be carefully watched and the patient warned as to the possible appearance of glaucoma, that he may observe whether any other symptoms present themselves.

The optometrist should also be on his guard against an error frequently met with, that a sense of fulness or tension within the eye, experienced by the patient, is any proof of increased intra-ocular pressure and hardness of the eyeball. For this feeling of fulness has been known to exist without the slightest increase in the tension of the ball.

Another common error is to suppose that all acute inflammations of the eye are accompanied by an increase in the intra-ocular tension. If, however, the degree of tension should be found to be increased, it must be regarded as a dangerous complication which is to be carefully watched, lest it be the forerunner of an attack of glaucoma.

3. *Subjective Appearances of Light and Color as Evidenced by a Halo or Rainbow Around a L ght.* This is also a very constant symptom of the premonitory stage of glaucoma. When looking at a gas-light or candle-flame, the patient sees a colored halo or rainbow around the light, the outer edge of which is red and the inner bluish-green.

This has been supposed to be due to an interference with the proper refraction of the rays of light, owing partly to slight opacities in the media, partly to the dilated pupil, and partly to some changes in the peripheral portion of the lens.

This colored ring seen around the light, and which is such a marked symptom of glaucoma, is the more noticeable the more the pupil is dilated, and disappears when the patient looks through a pin-hole disk. The stooping position sometimes brings it on, and as this position favors congestion of the blood-vessels, we must regard the latter as a possible factor in the causation of the ring.

4. *Ciliary Neuralgia.* A very marked symptom of glaucoma is pain, more or less acute, both in the eye and in the forehead and temples, radiating over the corresponding portion of the head and passing down the side of the nose. The pain sometimes occurs at a very early period of the disease, but occasionally it is not felt until a later stage, and, in some very rare cases, it may even be entirely absent. The pain is often very violent.

The severe neuralgic pains are undoubtedly due to pressure upon the ciliary nerves in the sclerotic, caused by the more or less sudden increase of tension. Sometimes this neuralgia extends to other branches of near-by nerves.

5. *Dilatation and Sluggishness of the Pupil.* When the pupil of an eye affected with the premonitory symptoms of glaucoma is compared with the pupil of the other eye (supposing it to be healthy), it will be found somewhat dilated and sluggish (or even immobile), and reacts but slightly if any, to the stimulus of light.

This sluggishness of the pupil is a well-marked symptom of the premonitory period of glaucoma, but the dilatation of the pupil is not so pronounced then as in the advanced stages of the disease, when it becomes widely dilated and quite immovable. The dilated pupil is sometimes oval in shape, with its long axis vertical.

This condition of the pupil may be due to interference with the function of the retina, to anæmia, of the iris, and to paralysis of the ciliary nerves supplying the iris, all of which, in turn, are the direct result of the increased pressure.

6. *Periodic Dimness of Vision.* The patient is troubled with occasional attacks of temporary obscuration of sight. At such times surrounding objects appear veiled and indistinct, and as if they were shrouded in a gray fog or smoke. The degree of dimness varies considerably, as does also the duration of the attacks; sometimes they last for only a few minutes, and again they may persist for several hours.

These attacks may also cause a slight contraction of the field of vision, but generally there is indistinctness of certain portions of the field. These attacks are usually caused by disturbances in the circulation of the eye, producing a temporary cloudiness of the aqueous and vitreous humors. Similar obscurations may be caused and imitated by pressure upon the healthy eye.

The impairment of vision is, perhaps, not so much due to the direct pressure upon the retina, as in the interference with the circulation, the fulness and stagnation of the veins, and the emptiness of the arteries. The truth of this seems to be proven by the fact that attacks of dimness of vision can be brought on by anything that causes congestion of the blood-vessels of the eye, as for instance, a full meal, great excitement, long-continued stooping, violent exercise, etc.

7. *Cloudiness of the Aqueous and Vitreous Humors.* The

aqueous humor is often found slightly but uniformly hazy, rendering the structure of the iris somewhat indistinct, and causing a slight change in its color. The vitreous humor, in like manner, becomes uniformly a little clouded. This haziness of the humors is very variable in its duration and degree, in some cases being so slight as to be hardly perceptible, and in other cases so marked as to render the fundus invisible through the ophthalmoscope.

The cause of the cloudiness is an exudation, partly inflammatory in its character, and partly the result of venous stasis. It may come on frequently, only lasting a few minutes, or it may be less frequent and last longer.

8. *Venous Congestion.* The congestion of the ciliary veins is usually slight during the premonitory stage of glaucoma, but they become tortuous and dilated in the later stages of the disease. An ophthalmoscopic examination shows the retinal veins also to be enlarged, with sometimes a venous pulsation.

9. *Arterial Pulsation.* This may be seen on the optic disk by means of the ophthalmoscope, and is always to be considered a sign of disease. This pulsation is a symptom of great importance, and it should be noted that it never occurs beyond the margin of the disk.

10. *Contraction of the Field of Vision.* This contraction of the field usually commences at the inner or nasal side, and extends thence toward the center and also above and below, until, finally, in the later stages of the disease only a small portion of the field remains at the outer side.

11. *Diminished Transparency of the Cornea.* The cornea loses its brightness and polish and its surface takes on a perculiar steamy appearance, resembling a piece of glass that had been breathed upon. This is due to œdema of the corneal tissue and its epithelium by infiltration into them of the intra-ocular fluids by reason of the increased tension.

12. *Diminution of the Depth of the Anterior Chamber,* from pushing forward of the lens and iris.

13. *Cupping or Excavation of the Optic Disk.* In the later stages of the disease, if the refractive media are sufficiently clear to allow of an ophthalmoscopic examination to be made, and if the pressure has been severe enough to produce the change, the disk is seen to be cupped or excavated. The whole surface of

the disk is cupped, and even though the excavation is but slight, the edge is always abrupt and precipitous, and it may even overhang the cup.

DIAGNOSIS OF GLAUCOMA.

We have given considerable space to an enumeration and description of the symptomatic indications of glaucoma, because it is important that the optometrist should be able to recognize this dreadful disease, not for purposes of treatment, but in order that he may not confound it with presbyopia, and thus fall into the fatal error of prescribing glasses for a disease which needs the treatment of a surgeon. This is an error that has occurred on more than one occasion, but it is one that should never occur in the practice of an optometrist.

The popular prejudice that has arisen, and not entirely without cause, as to the pernicious effects of wearing convex glasses which are too strong, can be traced to the fact that one of the premonitory symptoms of glaucoma, as mentioned above, is a rapid failure of the accommodation, and a consequent frequent demand for stronger and stronger glasses.

As glaucoma is more apt to occur at the presbyopic period of life, before the etiology and pathology of this disease were thoroughly understood, optometrists with many cases that come to them every two or three months for stronger and stronger glasses, which sufficed for a little while; and then, in turn, had to be changed for still stronger ones, until, finally, glasses were no longer of any use, and the patient became almost entirely blind. What is more natural than for the optometrist to associate the use of the strong glasses with the blindness, in the relation of cause and effect?

The lessons to be learned from this error are, in the first place, that strong glasses, in themselves, are not necessarily harmful, although they may produce some discomfort if they disturb the natural relation that should exist between the functions of accommodation and convergence. Evidence of the harmlessness of the continuous use of a single strong convex lens is seen in the case of watchmakers and engravers, among whom the wearing of such a lens is a necessary condition of their occupation, and who do not seem to suffer therefrom, but rather appear to enjoy an enviable immunity from diseases of the eye. The fact is, that the habitual exercise of the eye upon fine work, as, also, the normal use of any organ of the body, tends to the development and to the preservation of its powers.

The second lesson to be learned is, that the premature demand for strong glasses may arise from the existence of some diseased condition; and hence, the circumstance that glasses are required at an early age, or that stronger and stronger ones are called for at short intervals by a person not originally hypermetropic, thus proving the abnormally rapid failure of the accommodation, should be a reason for placing the optometrist on his guard against the possible approach of this dread disease, glaucoma, and for suggesting the advisability of seeking the skilled advice of a physician in time.

All of the symptoms mentioned above are not present in every case of glaucoma, and many of them may be so slight as to escape detection in the premonitory stages of the disease, when it falls under the observation of the optometrist, as being, perhaps, only an aggravated condition of presbyopia. The intensity of the symptoms will, naturally, vary with the severity of the attack, becoming very marked and extreme in sharp attacks of the disease, when, of course, it is beyond the stage at which it may be mistaken for a symptom of presbyopia, and when it is no longer difficult to make an accurate diagnosis.

RECOGNITION OF GLAUCOMA.

When a patient presents himself to an optometrist, after the lapse of only a few months, with the statement that his glasses no longer suffice, and with the request for stronger ones, and when the optometrist finds there has been a sudden and rapid diminution of the amplitude of accommodation, and when the patient complains of the occasional appearance of colored halos around the flame of lamps or candles, accompanied with attacks of fogginess of the general vision, then the optometrist must be on the lookout.

If these symptoms are accompanied with severe orbital pains, slight opacity of the aqueous humor, and sluggishness of the pupil, or an immobile pupil partly dilated, the optometrist must be still more on the alert.

If, in addition, the eyes present all the appearances of an acute inflammation with discoloration of the iris, and a steamy cornea insensible to touch, and if the acuteness of vision is very much impaired, then let the optometrist beware.

If the optometrist be on his guard for these symptoms, he cannot fail to recognize them, when present, in any case that falls under his examination; and, when recognized, the well-read man understands their import, and is in a position to give intelligent advice, without falling into the error of prescribing glasses for a supposed case of presbyopia. This timely advice may be the "stitch in time" that saves the eye from the second and third stages of glaucoma and blindness.

No more telling argument could be used by physicians against the advisability of allowing optometrists, or any one outside of the medical profession, to prescribe glasses for defective vision, than to find a case of irremediable blindness as the result of glaucoma which had been in the hands of an optometrist and treated as a case of presbyopia, and thus the real nature of the trouble was never discovered until the sight had been irreparably destroyed.

Such an occurrence would react against the individual optometrist who was the unfortunate cause of it, and against optometrists as a class, while, at the same time, the innocent sufferer would pay the penalty with his sight, which, once lost, could never be regained. This is a hard lesson for any one to learn from actual experience and we trust no reader of OPTOMETRIST'S MANUAL may ever be called upon to pass through such an experience.

Of course, no optometrist would knowingly make such an error, or willingly place in jeopardy the sight of one of his patrons, neither should the patient be compelled to run the risk of having the one chance of the restoration and preservation of vision denied him by the lack of knowledge of the optometrist whom he consults and in whom he places his confidence.

JEALOUSY OF THE MEDICAL PROFESSION.

Physicians and oculists are annoyed and alarmed, more than they will admit, at the encroachments made upon what they consider their territory by the educated and graduate optometrist of to-day. There is a large and ever-increasing number of persons who have their eyes examined and glasses adjusted by optometrists, and without the advice of a physician. Middle-aged persons who needed glasses only for the correction of presbyopia, always purchased them of opticians or jewelers, and formerly the trade of the optician was confined to this class of cases.

But in recent years the optician has developed beyond a mere seller of spectacles; he has shown a laudable desire to educate himself, and to adjust spectacles from a scientific standpoint. Not only this, but he has familiarized himself with the methods and instruments necessary for a thorough examination of the physical, as well as the refractive, condition of the eye. As a consequence of this more complete preparation for his work, the field of the optometrist has enlarged considerably, and his practice is no longer limited to the sale of spectacles for the relief of aged sight, but extends to the successful correction of all the optical defects to which the eye is subject, and even to the relief of complicated muscular anomalies.

This, naturally, has aroused the antagonism of the medical profession, inasmuch as it has diverted a large stream of profitable trade from the office of the oculist into the parlor of the optometrist. There is an old saying that a man can be touched or influenced through his pocket-book more quickly and potentially than by any other means, the truth of which remark is very aptly exemplified in the attitude assumed, and enmity shown, by the medical fraternity toward the optical profession. This is exhibited, not only by the physician in his daily walk and talk, but is reflected on the pages of the various medical journals.

The position physicians assume is that no one but a medical graduate is competent to prescribe glasses, and, therefore, they feel it their duty, in the interest of the public, to warn people against the very great danger of wearing any pair of glasses not prescribed by an oculist, and they lose no opportunity to give optometrists a "black eye."

A CASE IN POINT.

The following is an abstract from an editorial article in a leading medical journal:

"The observation of careful ophthalmologists indicates that many individuals are given glasses which are worse than useless, and that. in some instances, so much valuable time is lost that subsequent intelligent treatment is of no avail—some of these are cases in which, if a proper ophthalmoscopic examination had been made and suitable drugs had been prescribed, the patient would have retained vision.

"Such a case recently occurred in this city, where a young woman found her vision failing, and, on the advice of her friends, went to an optician, who examined eyes without charge, sold her a pair of glasses, and sent her home with the assurance that all she needed was 'rest glasses.' A few weeks passed by, during which her vision grew gradually worse. Another consultation with the optician was held, and another pair of glasses was prescribed. This performance was gone through with twice more, with four changes of glasses in six months; and by this time the patient's vision was reduced to counting fingers at a distance of five feet. At this time an ophthalmoscopic examination revealed the unfortunate fact that the patient had post-neuritic atrophy of both optic nerves."

This is an exceptional case, and, if it occurred just as related (which we have no reason to doubt), it is much to the discredit of the optician implicated. No man who carefully reads The Manual and follows its teachings could fall into any such grievous error. An optometrist, competent to examine eyes and adjust glasses (and none other should be allowed in the business), could not fail to see there was some unusual and serious trouble in this young woman's case, which called for attention other than the fitting of glasses. No reader of this book would assure such a patient that all she needed was rest glasses.

In cases of defective vision, the optometrist must discriminate between those which can and those which cannot be helped by glasses. This divides all cases into two great classes, and we have indicated how the optometrist can determine to which of these classes his case belongs. In the first class of cases he is justified in assuming the sole management; while, in the second class of cases, our teaching has been that an ophthalmoscopic examination should always be made by the optometrist himself if he is prepared to make it, or by an oculist to whom the patient may be referred to by the optometrist. By following out this line of procedure, the optometrist saves his reputation and the patient saves his sight, while the medical profession is saved much needless anxiety about the danger of wearing glasses prescribed by an outsider.

Another case mentioned in this article is that of a little girl who was found wearing concave glasses given her by an optician, when an examination showed that she was exceedingly far-sighted. We admit this is a serious error, and one that should not, and will not, occur in the practice of a careful and competent optometrist.

ANOTHER UNFORTUNATE CASE.

The previous case, where concave glasses were given in hypermetropia, recalls a case whose history was given in a widely-read medical journal, and the result severely commented upon, to the discomfiture of the prescribing optician.

The patient was a young lady aged twenty-five, who stated that four weeks previously she had noticed a haziness in the right eye, followed, in a few days, by floating black spots, and later she suddenly lost the sight of the eye in question. This lady had always been near-sighted, and only a short time before the above-mentioned symptoms made their appearance, a jeweler (who happened to be her brother) changed her glasses for stronger concave ones, at which time she was able to read and see clearly.

An oculist, who was now consulted, found the vision of the right eye was for fingers only, while the left eye was barely able to perceive large objects. An ophthalmoscopic examination revealed a detachment of the retina in the right eye and a posterior staphyloma in the left. The ordinary treatment for detachment of the retina was instituted, but a consultation with a view to operation was refused. The result is that she is blind in the right eye from the detachment of the retina, and the left eye for a long while had been useless.

The oculist argues that, if an ophthalmoscopic examination had been made at the time the glasses were changed and when the unpleasant symptoms first made their appearance the condition of the fundus of the eye would have shown sufficient indications of danger to have warranted putting the case under treatment before irreparable damage had been done, and thus the only chance for successfully treating the case was lost. Hence, the ground is taken in the article that the trained physician (the oculist) is the only proper person to prescribe glasses, and not the optometrist or the jeweler.

The medical journals say it would not be hard to multiply illustrations of the injurious effects of prescribing glasses in cases like the above. At the same time, they admit that this practice does not extend to all optometrists, but that there are a few honorable exceptions, who refuse to furnish glasses when they discover visual defects. However, they think that too many dealers in spectacles have no compunctions about usurping the province of ophthalmologists, and yield to the temptations of profit and the unwise solicitations of their customers to do what they have no right to do.

One of the articles referred to closes as follows: "If the prescriber of glasses possesses the skill to use the ophthalmoscope, and is able, also, to correctly interpret the various shades of normal and subnormal retinæ and optic nerves, vitreous and choroid, then I should be the last one to deny him the privilege of prescribing glasses, be he oculist or optometrist. Lacking this special knowledge and skill as a refract onist, I would be the first to sound the warning to him personally, and use his ignorance in an impersonal manner to warn others."

This is an honest expression, and it is the only proper view to take of the whole matter under the circumstances mentioned; but it must be remembered that the influence of the various optical colleges, the optical teachings of journals like The Keystone Magazine of Optometry, and the progressive spirit manifested by optometrists everywhere to study their profession from a scientific standpoint, have served to place the optometrist of to-day so far beyond his brother of twenty-five years ago that there can be no comparison between them; and, therefore, while the cases narrated above, and the deductions and arguments of the various medical journals thereon, might hold against the back-number optician of a score of years ago, they cannot apply, as a class, to the studious and well-informed optometrist of to-day.

OCULIST *vs.* OPTICIAN.

The medical profession are willing to allow no one to fit and prescribe glasses who is not competent to use the ophthalmoscope and to interpret what it reveals, and they thus think they are shutting out all except physicians. The fact is, that not very long ago this instrument was reserved for physicians' use alone, and it was considered entirely beyond the optometrist's province. But the time has arrived when optometrists, as a class, are demanding instruction in the use of the ophthalmoscope, the employment of which they claim as one of their privileges.

That an ophthalmoscope should be included in the outfit of the well-prepared optometrist, there can be no doubt; but its exact status is still a matter of question. Some optometrists seem to have such an exalted opinion of this instrument as to think it possesses some mysterious power by which to reveal to them the particular glass required by each individual case. But perhaps the best advice to the optometrist employing an ophthalmoscope is not to use it for refraction purposes, that is, not to attempt to measure the optical defect and prescribe glasses by means of the ophthalmoscope.

It would be well for optometrists to regard this instrument simply as an aid in the examination of difficult cases. Where there is great impairment of vision, and where there is difficulty in restoring vision by the trial-case, then, in such cases, an ophthalmoscopic examination is of value to show the condition of the refractive media, of the optic nerve and retina, and of the whole interior of the eye, and to reveal the presence of any pathological condition that may be present, thus explaining the cause of the impaired vision, and indicating whether glasses or medical treatment is needed.

THE PROVINCE OF THE OPTOMETRIST.

While refraction work comes legitimately within the province of the qualified optometrist, no one should be considered an optometrist, and, therefore, no one should be allowed to adjust glasses, who has not received special instruction in this work.

For this reason it is imperative that the intending optometrist forsake, as being imperfect and unsatisfactory, the old way of acquiring a knowledge of the optical business by service behind an optician's counter, and by picking up such a smattering of the science of adjusting glasses as may fall from his employer's lips, or as may be observed from a careful watching of his methods.

THE VALUE OF THE INSTRUCTION IN OPTICS.

While such an experience must not be decried, nor its practical value underestimated, the intending optometrist must convince himself of the necessity of adding to and supplementing it by classified instruction in the theoretical and scientific principles underlying the science of optics, and including the entire field of study covering the subjects in which an optometrist should be particularly interested. The field is so extensive as at first sight to be appalling, but this should only serve to stimulate the student in his efforts to comprehend it and familiarize himself with it.

The optical student must first acquire a knowledge of the anatomy of the eye and the physiology of vision, then of the principles of optics, the laws and properties of light, its refraction by transparent media of different density, and an acquaintance with the various kinds of lenses, and their action on rays of light that pass through them. With these matters thoroughly understood as a broad and firm groundwork, the refraction and accommodation of the emmetropic eye should then be considered and carefully studied.

THE AIM OF THE OPTOMETRIST.

The ultimate aim of all the studies of the optometrist is to learn to recognize and correct the various forms of ametropia, and, therefore, while it is desirable for him to be well read and well informed on all matters pertaining to his business, it is still more important for him to be able to put his theoretical knowledge into practical use. It is possible for a man to comprehend the theory of a science and yet be unable to put it into practical effect.

The tendency of modern teaching, from the class-room of the primary school to the lecture-hall of the university, seems to be to cram knowledge into the scholar's cranium by the stuffing process, leaving to Nature, or to accident, or to environment, or to the scholar himself, the development of the ability to make practical use of his knowledge, if, perchance, it is ever developed.

ABSTRACT KNOWLEDGE DOES NOT ALWAYS MEAN SUCCESS.

Many instances of this can be found in the case of medical men. It is no trouble to point out physicians of talent and large scientific attainments, who are not nearly so successful as some of their less-educated brethren; the reason being that the one is too scientific and loves science for the sake of knowledge alone, while the other is more businesslike, and is interested in science only so far as he can make practical use of it. This is likewise true of optometrists; it is possible for a man to thoroughly comprehend the structure of the eye and be familiar with the laws of optics, and yet prove himself a very poor optometrist when it comes to recognizing optical defects and adjusting glasses.

While education in the abstract is essential, it is, nevertheless, true that no matter how well educated a man may be, his education loses half its value if its possessor is unable to make practical use of it. This is well illustrated by money, which is something we all esteem most highly, which we are constantly striving after, and of which we feel we cannot have too much. And yet the value of money lies not in the money itself, but in its purchasing power. As long as it is hoarded up and hid away it is of no use, but it is only of value for what it will buy; hence a man may possess a great deal of money, but if, for any reason, he is unable or unwilling to spend it (as in the case of the miser), it is valueless.

While it is all very well for the public to know that the optometrist has carefully studied his science, yet the main thing, after all, is their confidence in his ability to properly fit their eyes with glasses when their sight becomes impaired by some optical defect. This is his actual business as an optometrist, and it is as such he should strive to be successful.

A PROFITABLE DIGRESSION.

The foregoing has been a digression from our subject proper —presbyopia—a digression we trust not without profit. The consideration of the symptoms of presbyopia, with its accompanying eyestrain and other evidences of asthenopia, and the necessity for their correction by glasses, if due to presbyopia, and the question whether a similar train of symptoms might not indicate the possible approach of some serious disease of the eye incident to the presbyopic period of life, led us to a somewhat detailed description of glaucoma, the disease most to be feared, and the one most frequently met with, which cannot fail to be of benefit to those who have carefully read it.

The danger to the patient's eyesight, if this disease was not recognized, or if it was confounded with the physiological change of presbyopia, and the disastrous effect such an error would have on the reputation of the optometrist who made it (if, indeed, it did not render him liable to a suit for malpractice), opened up the much-distressed and never-to-be-settled question of oculist *versus* optometrist, and just where the province of the one ends and the other begins. Feeling that no apology is needed for this digression, we pass on now to the

TREATMENT OF PRESBYOPIA.

The essential principle of presbyopia being a loss of convexity of the crystalline lens, and a diminution in the refractive power of the eye, what more natural than to supply a convex lens before the eye to supplement the diminished convexity of its dioptric system? Therefore, the treatment of presbyopia resolves itself into the adaptation of the proper convex spherical lenses.

The correction of presbyopia by convex lenses is not quite "as old as the hills," but it dates back some six hundred years, and probably longer, and, therefore, to us who are accustomed to the rapid changes and improvements of the culmination of the nineteenth century, it seems so long as to have always existed. The betterment of the vision of old age and the relief of presbyopia called for some remedy, and our ancient forefathers proved themselves equal to the task of supplying it.

THE PAST CONTRASTED WITH THE PRESENT.

How rude and clumsy and imperfect those old-time glasses are when compared with the neat and elegant spectacles and eyeglass furnished by the optometrist of to-day! But they served their purpose well, and probably afforded more satisfaction to the simple needs of the scholars of that day than does a pair of our present faultless eyeglasses to the fastidious tastes of the men of our day. Then they were considered a luxury, and received the most careful attention in strong contrast to the careless manner and thoughtlessness with which they are treated at the present time.

Notwithstanding the improvement in the grinding of lenses and the manufacture of frames, and their better adaptation to the face of the wearer, there has been no change in the principle on which they are prescribed, and the convex lens of the thirteenth century acted in the same way in relieving and assisting the vision of old age as does our much-advertised glass of the nineteenth century. There has been marked advance in the science of optics in the past quarter of a century, notably in the recognition and correction of astigmatism, and the detection and treatment of muscular anomalies, not to mention the more scientific management of hypermetropia and myopia; but in the case of presbyopia we are not much ahead of our old-time predecessors.

THE CORRECTION OF PRESBYOPIA IS NOT A NEW DISCOVERY.

And, in fact, this is a condition in the treatment of which there does not seem to be much room for improvement or advance. As explained in the early part of this chapter, it is not an optical defect, nor is it to be considered in any sense an abnormal process; but it is simply a natural change, a physiological condition that is common to all mankind, and consists in an impairment of the power of accommodation and an inability to change the focus of the eye so as to adopt it for the divergent rays proceeding from near objects.

The problem to be solved, and the result to be attained, is to add, in an artificial way, sufficient refractive power to the failing accommodation to maintain the clearness and comfort of close vision.

The sum and substance of the correction of presbyopia is the addition of artificial convexity (in the shape of a convex lens on the outside of the eye), to supplement the diminished convexity of the crystalline lens, and this is the reason that the correction of presbyopia is such a simple matter, and explains why no advancement has been possible over the first correction of six hundred years ago.

THE PRINCIPLE ON WHICH THE CORRECTION OF PRESBYOPIA DEPENDS.

The main symptoms of presbyopia, and the external evidence of the senile changes taking place in the eye, is a recession of the near point beyond a comfortable and convenient distance. A gradually receding near point applies to every age of life; it is not an accompaniment of age alone, since it commences as early as the tenth year; but it is only when it has reached an inconvenient distance, which is usually about middle age, that it begins to be noticeable and cause its own peculiar symptoms, and calls for relief.

Therefore, when the near point has receded beyond eight inches, it has reached a point when it is beginning to blur the sharpness of vision for near objects, and the individual feels the need of some assistance to clear up the vision, and then we look upon the case as one of presbyopia.

RECESSION OF THE NEAR POINT THE ESSENTIAL FEATURE.

Such being the case, and the recession of the near point being the essential feature of presbyopia, the principle on which its correction depends is to furnish a convex lens that will bring back this receded near point to eight inches, which distance experience has shown to be a convenient one for reading and writing, and the limit beyond which the eyes can be used only with effort and strain.

We can scarcely imagine the condition of mankind without convex glasses, nor the effect produced on the march of progress by the possible withdrawal of presbyopic lenses. Without them, persons, as they reach middle life, would be compelled to abandon occupations that require sharp vision for small objects, and desirable positions that had been acceptably filled for so many years would, of necessity, have to be relinquished. In order to be able to continue reading, books and newspapers would have to be printed in larger letters, and the size of the type would have to be graded according to the degree of the presbyopia.

Imagine a customer going into a book-store and inquiring for a book suited to the vision of a man fifty years of age, a newsboy crying out his papers as being printed for gentlemen sixty or seventy years of age, or papers of types to suit the ages of all customers.

THE NATURAL FAILURE OF VISION.

The eye is the most useful, as it is the most wonderful, of all our organs of special sense, and the sense of sight differs materially from all the other special senses, as does the eye differ from all the other organs of the body. In spite of the marvelous mechanism of the eye (or, perhaps, because of it), and although it is such a valuable possession of the human race, it is the only organ in the whole range of the human system that naturally fails in functional strength and requires artificial assistance.

The more one dwells on this point the stranger does it seem, and although the God of Nature surely had some wise purpose in view in causing the eye to be subject to these senile changes, He has seen fit to withhold the reason from our perception. It is certainly not because the eye is in continuous use or that it does not enjoy intervals of rest and repose, for the fact is, that sleep affords the eye an opportunity for complete rest, and hence the eye is quiescent for seven or eight hours out of every twenty-four. In the case of the presbyope, where the difficulty of near vision is just beginning to manifest itself, at about the age of forty-five, if the individual has received his normal allowance of sleep the eye has been closed for fifteen years of this time.

This is in marked contrast with the heart, which is never quiet, but contracts and dilates seventy times in every minute every hour of the day, every day of the year, and every year of our life, day and night, asleep or awake, from the cradle to the grave, and without ceasing its work for a single minute, even though the individual reaches a patriarchial age.

One could hardly wonder if this faithful organ would occasionally ask for a moment's repose, or if it would require the crutch of artificial assistance after years of sleepless service. But an all-wise Creator has seen fit to endow the heart with such tireless fibre and vigor that there is no natural abatement of its force, and only disease and death can still it.

CONVEX LENSES A BOON TO THE AGED.

Such being the case, and the function of sight depreciating so much with the advance of years as to become useless for near vision, what a priceless boon the individual finds in convex spectacles properly adapted! They completely neutralize and overcome the senile defects in the eye, and restore vision to its normal clearness for small objects, and place the presbyopic individual on the same plane, as regards near vision, as his neighbor twenty years younger. By a change of lenses for stronges ones, from time to time, as the degree of presbyopia increases with the addition of years, the near vision is maintained sufficiently clear for all practical purposes until a very advanced age, unless some diseased condition intervenes.

DIAGNOSIS OF PRESBYOPIA.

Ordinarily, if the presbyopia is uncomplicated, it can be easily recognized, and is not likely to be confounded with any other defect. We say "with any other defect," but we do not look upon presbyopia as a defect; it is a physiological change, a natural failure of sight, and should not be classed among the defects to which the eye is subject.

In emmetropic eyes presbyopia makes its appearance soon after the fortieth year, at which time the patient seeks a better illumination, prefers a larger type, and begins to hold his book farther off. The distant vision is unaffected, and in every other way the eye is normal. There is no difficulty in recognizing this as a case of commencing presbyopia.

The diagnosis of presbyopia depends on three factors:

1. Distant vision is perfect; or, in other words, the refraction is normal.

2. Near vision is indistinct, and reading type must be held farther and farther from the eyes.

3. The age of the patient: Presbyopia never occurs in an emmetropic eye under the age of forty.

When these three conditions are found in any case, there can be no mistake in classing it as presbyopia; and unless all three of these conditions are present, it cannot be a case of presbyopia.

The near vision may be impaired by the various optical defects, and also by organic disease of some of the structures of the eye; but in these cases the distant vision suffers in the same distant vision remains perfect in presbyopia, while it is impoired proportions, so that the diagnosis seems to hinge on the fact that distant vision remains perfect in presbyopia, while it is impaired in every other deficiency of sight with which it may be confounded. In other words, presbyopia is an error of accommodation (which refers to near vision), and not an error of refraction (which refers to distant vision).

GRADE OF PRESBYOPIA.

Inasmuch as a recession of the near point is the essential feature of presbyopia, the degree of the defect will depend on the distance to which the near point has receded, the greater the distance of the near point the higher the degree of the presbyopia; and it will be measured by the strength of the convex lens necessary to restore the near point to a convenient distance.

The near point of distinct vision begins to recede as early as the tenth year of life, at which age it is not more than three inches from the eyes. This recession is not noticed either by the person himself or by his friends, and occasions no inconvenience in the use of the eyes until it has reached eight inches, which usually occurs about the fortieth year of life. At this time reading and writing and close work are accomplished only at the cost of some strain, and then a weak convex lens should be supplied at once, to assist the enfeebled accommodation, to increase the size of the retinal image, to restore the receded near point, and to relieve the strain on the eyes.

This is the proper principle to be followed in the management of presbyopia, to recognize it early, and to supply a weak convex lens at once; this tends to preserve and conserve the sight unimpaired the longest possible time, and places the eye in the best condition to retard the senile changes.

It seems, however, as if the majority of people are guided by advice just the opposite of this; instead of putting on a weak convex lens just as soon as the failure of sight is perceptible, the natural tendency (perhaps in illustration of the perverseness of human nature) seems to be to delay the wearing of glasses as long as it can possibly be postponed, to the detriment of the eye and the increased impairment of its accommodation.

PREJUDICE AGAINST GLASSES.

Many persons are prejudiced against the wearing of glasses, and sometimes positively decline to use them, even when they are imperatively needed. They may be sensible persons, and display good judgment in all other matters, but in this one respect they act most foolishly and without any reason. A contest with age is hopeless, and it is the part of wisdom to yield gracefully to the first summons to surrender.

PERHAPS IT IS PRIDE.

Undoubtedly a feeling of pride is one of the chief drawbacks that tends to make people hesitate about commencing to wear glasses, and the fear that it would be an open acknowledgment that they are growing old. This is especially the case with ladies, and it seems to be with them an argument that is almost unanswerable, and instead of yielding and growing old gracefully, they endeavor to hide the fact that their sight is failing; or, if it becomes evident to others, they make all sorts of excuses for it, and try every other means of improving it that is recommended, except the one proper remedy, viz.: glasses.

This proves itself a matter of contention for the optometrist, and oftentimes his tact and judgment will be severely strained in his efforts to convince people of their simple duty.

WHAT IS THE NUMBER OF THE FIRST GLASS USUALLY GIVEN IN PRESBYOPIA.

A little thought will show that the number of the glass first prescribed in a case of presbyopia will depend entirely on the degree of the impairment of vision present when the glasses are first desired. If glasses are sought as soon as the symptoms of presbyopia first begin to manifest themselves, a + .25 D. or a + .50 D. lens will usually suffice; but if the person refuses to wear glasses, and persists in reading without them, and strains his eyes for several years after the need of glasses is first felt, then a weak convex lens is no longer sufficient, but a + 1.50 D., or even a + 2 D., may be required; and, therefore, if a + .50 D. lens is prescribed in such a case, there is disappointment to both.

If the eyes are tested separtely in presbyopia, the degree of the defect will seem greater, and stronger glasses seem indicated, than when the eyes are tried together. The reason for this is, that when both eyes are used and the convergence brought into play, the accommodation is stimulated thereby and its amount increased, therefore, the binocular near point (by the use of convergence) is nearer to the eyes than the monocular near point (without the employment of convergence); and hence, the accommodation being greater, the degree of presbyopia is lessened. It follows, then, that those glasses which would be suited to each eye separately would be too strong when the eyes are used together in binocular vision.

THE ASSOCIATION OF ACCOMMODATION AND CONVERGENCE.

As has been already explained on these pages, there is an intimate relation normally existing between the functions of accommodation and convergence, which is more or less disturbed by the presbyopic failure of the accommodation. This sundering of two functions which have worked hand-in-hand for many years cannot occur without producing some disturbance of vision, which will interfere with the comfortable use of the eyes, and will manifest itself by various symptoms and indications of irritation.

In order to preserve as much as possible the harmony between accommodation and convergence, prisms are sometimes employed, combining them with the spherical lenses, so that, while the spherical element of the combination assists the accommodation, the prismatic element will assist the convergence, provided they are placed over the eye base inward.

Similar in action to these sphero-prisms are *decentered lenses.* They are ground in the frame in such a manner that the wearer looks through a portion of the lens to one or the other side of its optical center, and the curved portion of the glass that is thus used for vision furnishes a slight prismatic action.

If the student will recall the construction of spherical lenses, as described in the earlier chapters of this work, he will readily understand how a spherical lens is capable of acting as a prism when the rays of light pass through the peripheral portions of the lens.

It will be remembered that a convex spherical lens is composed of an indefinite number of prisms, with their base joined together at the optical center of the lens, and a concave spherical lens is similarly composed, with the apices of the prisms joined together at the optical center of the lens.

Hence its follows. when it is desired to decenter a convex lens so as to assist the convergence, the displacement is inward, and then the prism is presented to the eye with its base inward; whereas, in concave lenses, the decentering is outward in order to obtain the prism with its base in.

ORTHOSCOPIC LENSES.

As a substitute for the regular spherical lenses, and for the sphero-prismatic combination, Dr. Scheffler proposed, some years ago, the employment of what he called "orthoscopic" lenses These lenses are composed of the same two elements, a sphere and a prism, but so nicely balanced and proportioned that the amount of assistance furnished the accommodation and the convergence should exactly correspond.

As the convex spherical lens removes the necessity for any effort of accommodation, and the prism removes the necessity for any effort of convergence, an object held at the focal distance of the spherical lens may, consequently, be seen for an indefinite period of time without any muscular effort on the part either of the accommodation or the convergence.

It will be manifest, on a little reflection, that every convex spherical lens must have a corresponding prism which would stand in "orthoscopic" relation to it. The following table, which is only approximate, gives the number of the convex lens with the degree of the corresponding prism:

TABLE OF ORTHOSCOPIC LENSES.

.50 D.	1½°
1. D.	3°
1.25 D.	4½°
1.75 D.	6°
2.25 D.	7½°
3. D.	9°

While theoretically correct, the results are not so good as at first sight seems possible. One does not have to go very high in spherical lenses before the prism becomes so strong, and adds so much to the weight and thickness of the glass, as to practically prohibit their use, and limits the combinations (if employed at all) to the weaker numbers.

The test of such glasses being perfectly "orthoscopic" is that the two lenses, when fixed in their frame, should cast only a single image upon a card placed at their focal length; this naturally calls for careful adjustment.

Dr. Scheffler's original proposition was to cut these orthoscopic lenses from the peripheral portions of a very large lens, in order to obtain the decentering effect of this lens.

Hence, if these lenses are, or if we consider them to be, eccentric portions of one very great lens, we can readily understand why only one image is formed when they are properly fixed in their frame and held at their focal distance before a screen. A glance at the accompanying diagram will assist in making this point clear, as these marked portions, representing the orthoscopic lenses, are the parts through which the eyes would look if the one large lens was held up before the face with its center opposite the root of the nose; and, therefore, as the large

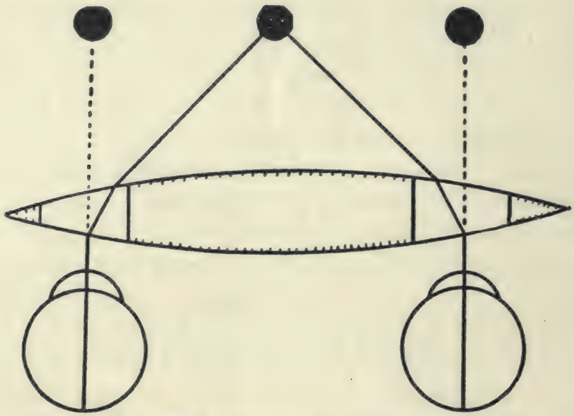


Illustration of orthoscopic lenses cut from periphery of a large lens.

single lens produces only a single image at its focal point, so should its two eccentric portions produce, in like manner, a single image at the same point.

GLASSES SHOULD NOT BE TOO STRONG.

In old age the convex glasses prescribed for the correction of the presbyopia should be sufficiently strong to magnify the image somewhat, so that it may cover a large nerve surface, and thus impress a greater number of rods and cones, and, in this way, partially compensate for the blunted sensibility.

In the commencement of presbyopia, on the other hand, and in the slighter degrees of the deficiency, and while the patient retains the normal vigor of middle life, the glasses prescribed should not be too strong. In these cases the thought should be kept constantly in mind that the object of the convex glasses is not so much to magnify the retinal images, as to bring the near point back to eight inches and restore the point of distinct vision to a comfortable and convenient distance from the eyes, and, at the same time, to make objects appear legible, and as nearly as possible of their natural size, or of the size they were before the eyes became presbyopic.

As previously explained, convex lenses simply add to the refractive power of the eye, and supply the loss in the power of accommodation incident to age; and when this loss is made good, the object for which the glasses are prescribed is fully accomplished. Any attempt to do more than this, by the use of stronger glasses, may lead to the production of injurious results.

While there are differences of opinion on this subject, many gentlemen of experience agree that their observations lead them to believe that numberless presbyopic persons, in wearing convex glasses, have seriously injured their eyes by the use of glasses too strong at first; and thus arose the necessity for changing them sooner and oftener for those of stronger power.

WHY STRONG GLASSES ARE APT TO BE HARMFUL.

The statement has been made that the use of strong glasses in the commencement of presbyopia is one of the factors involved in favoring and increasing more rapidly the customary senile changes in the crystalline lens and muscle of accommodation. The stronger the glass employed, the less the need of accommodative effort, and hence the ciliary muscle becomes relaxed from disuse, and even when it is called upon to contract its fibres and perform its function, it is only to a limited extent.

A continuance of these conditions results in an enfeeblement of the muscle of accommodation, which, as a consequence, loses its power to act beyond its accustomed point. This point soon becomes so fixed as to indicate the maximum tension of the muscle, beyond which it is impossible to go, and which point even cannot be long maintained. This requires the substitution, in a very short time, of lenses of a much higher power, in order to relieve the overburdened accommodation.

The same principle applies to the use of any other muscle in the body; the less it is used and the more it is assisted, the sooner it loses its vigor and tone. Hence, it follows that a normal use of any muscle or organ of the body is requisite for its maintenance in health and strength.

It should always be remembered that close vision is accomplished only by muscular effort, just the same as a voluntary act of any other portion of the body.

The employment of very strong convex glasses in the early stages of presbyopia not only weakens the muscle of accommodation by overassisting it, and thus allowing its fibres to become relaxed from disuse, but also hastens the senile changes in the crystalline lens, and favors the natural tendency for an increase in its firmness and solidity.

In youth, the crystalline lens is soft and yielding, and quickly responds in a change of shape at the slightest command of the ciliary muscle. Near vision calls for an increase in its convexity, and more distant vision allows a return to a flatter condition. During our waking hours there is, therefore, a constant shifting of the particles of the lens substance on each other, as the jelly-like body is modified in shape by the action of the muscle of accommodation.

As age creeps on, the lens begins to lose some of its original elasticity and softness, and as it grows firmer and harder an extra amount of muscular force is now required to produce the same degree of convexity of its surface. If, at this time, a strong convex lens be supplied, there will be very little need for muscular effort, and very little call for a change in the shape of lens. Therefore, as the motions of the particles of the lens substance on each other are less and less called for, the lens begins to lose its elasticity and becomes firmer, and offers increased resistance to the action of the ciliary muscle, which also is losing its original strength.

Both of these factors, acting and reacting on each other, favor an increase of the essential conditions of presbyopia, intensified, as stated above, by the application of strong convex glasses, which weaken the muscle of accommodation by removing the necessity for its exercise, and also favor an increase in the hardness of the lens by lessening the motion of its particles on each other, both of which factors react on the ciliary muscle by requiring an increased action from its already enfeebled fibres.

TESTING THE NEAR POINT.

In the commencement of presbyopia, if the test be made in good daylight, the patient may still be able to read ordinary print as close as eight inches, and the conclusion might be jumped at that presbyopia has not yet set in. But it should be remembered that the recession of the near point, and the other symptoms of presbyopia, first manifest themselves in the evening and by artificial light, and if the test be made at the same time and under the same conditions, the near point will be found to be farther away than eight inches, and, perhaps, nine or ten inches will be the closest point at which the reading type can be distinguished; and then the existence of presbyopia is at once recognized.

RULE FOR THE SELECTION OF GLASSES.

The number of the glass required to restore the receded near point to eight inches, or, in other words, the lens called for to correct any given case of presbyopia, may be obtained according to the following rule:

Subtract the glass which represents the receded near point from the glass whose focus represents the point which we wish to make the near point.

In making use of this rule, and working it out according to the metrical system, the beginner may have some slight difficulty at first; but a little practice will enable him to do it easily and quickly.

It should be borne in mind that a meter is equal to about forty inches (1 m. = 40 in.), and that a centimeter (written cm.) is equal to one-hundredth of forty inches 40/100 or 2/5 of an inch (1 cm. = 2/5 in.). It should also be remembered, as has already been described on these pages, that if the near point, expressed in centimeters, be divided into one hundred, the result will be the number of dioptres, which, in emmetropia, expresses the positive refracting power.

With these points well understood and constantly borne in mind, the optometrist is prepared to make use of the rule, and, in order to assist him, we will give several practical examples of it.

ACCORDING TO THE METRICAL SYSTEM.

Suppose he meets with a case in which the near point has receded to twenty inches. The first step is to reduce the inches to centimeters. Forty inches equal one hundred centimeters; twenty inches equal one-half of that, or fifty centimeters (20 in. = 50 cm.). We then divide this into one hundred in order to obtain how many dioptres of positive refracting power it represents ($100 \div 50 = 2$), which shows 2 D. as the glass representing the receded near point, worked out according to the above directions.

Now, as previously stated in the early part of this chapter, we define presbyopia as that condition of the eye in which the near point has receded beyond eight inches, and the treatment of presbyopia hinges on the restoration of the near point, and the bringing it back to eight inches, which is the point we wish to make the near point.

If forty inches equal one hundred centimeters, eight inches (being one-fifth of forty) will equal one-fifth of one hundred, or twenty (8 in. = 20 cm.). This, then, is to be divided into one hundred, in order to ascertain the number of dioptres of positive refracting power; twenty into one hundred equals five ($100 \div 20 = 5$), indicating 5 D. as the glass representing the normal near point.

Now, to repeat the rule, we subtract the glass representing the receded near point from the glass as we wish to make it, which, in this particular case, would be 2 D. taken from 5 D., leaving + 3 D. as the glass required to restore the near point to eight inches and correct this case of presbyopia.

By way of further illustration, we will take another case, in which the near point has receded to thirteen inches, which is represented by a glass of 3 D., according to the following calculation: 40 in. = 100 cm.; 13 in. = 33 cm.; $100 \div 33 = 3$. Then 3 D. is to be subtracted from 5 D., which leaves + 2 D. as the correcting lens for this imaginary patient.

ACCORDING TO THE INCH SYSTEM.

If the optometrist wishes to verify the results obtained as above, or if he is old fogyish enough to stick to the ancient inch system, and refuses to use the (new fangled) metrical system, the calculations can be made with fractions somewhat as follows:

We will take the illustrative case first mentioned above, in which the near point has receded to twenty inches, which is now to be subtracted from eight inches.

$$\frac{1}{8} - \frac{1}{20} = \frac{1}{13\frac{1}{3}}.$$

This involves a troublesome calculation in fractions, and illustrates most pointedly one of the chief objections to the inch system of numbering lenses. To some of us, who have been out of school for many years, and but little accustomed to manipulating fractions, a sum like this would be quite appalling

And to any one it means a sum more or less difficult of calculation, as the two fractions must be reduced to a common denominator, and then subtracted, and, finally, the result must be reduced or changed to its simplest form.

In the second illustrative case, in which the near point has receded to thirteen inches, we have to subtract from eight inches, which gives us the following nice little sum in mental arithmetic:

$$\frac{1}{8} - \frac{1}{13} = \frac{1}{208}$$

The optometrist who is acquainted with the rule for converting inches into dioptres, and vice versa, will see at once that the results in both cases correspond; in the first case the 3 D. lens is equivalent to a thirteen-inch lens, and in the second case the 2 D. lens is equivalent to a twenty-inch lens. The principle is the same and the result is identical, whether the inch or the metrical system be employed; but the latter is much to be preferred, for many reasons.

LIMITATION OF THE RULE.

Although a rule of this kind is very useful, and glasses can frequently be ordered by it with tolerable accuracy, yet it has its limitations, and the optometrist should not expect to closely follow it in every case that comes to him to be fitted. It is always well to bear in mind that the definition we have given of presbyopia, with reference to the recession of its near point, is entirely an arbitrary one, and that the optometrist should take into account the distance at which the individual has been accustomed to read, or at which he is required to work, and in this particular matter there is great variety.

Many small people work and read at eight inches, whereas very tall people may be uncomfortable unless the book they are reading is held fourteen or fifteen inches away. The distance for which the presbyope will require glasses also varies according to the occupation in which the person is engaged.

WHAT GLASS TO PRESCRIBE FIRST.

In the great majority of cases, + 1 D. will be the proper glass to prescribe in the commencement of presbyopia. It should be noted that this has reference only to the beginning of presbyopia, for it seems to be one of the failings of presbyopes that they will defer the wearing of glasses until the latest possible moment, many of them being thus actuated by a desire to conceal their age and retain their juvenility.

If, then, a person struggles along for several years after presbyopia has set in, by saving his eyes and surreptitiously using another's glasses, and does not come for examination until his near point has receded to arm's length, then a + 1 D. will not suffice, but a much stronger glass is required.

In some cases it may, perhaps, be advisable to commence with a + .50 D. lens, if the case is seen at the very outset of the presbyopic symptoms. When, as will happen after awhile, on account of the steady decline of the accommodation, still more power is required, the glasses may be strengthened by a half dioptre, as occasion requires; the stronger ones being especially needed when artificial light is used, as the symptoms of presbyopia are always magnified at night.

Remarkable evidence of the apparent harmlessness of continuous working by the aid of a single strong convex glass is furnished by watchmakers, among whom such work, under such circumstances, is an unavoidable condition of their calling, and who do not appear to be any more liable to eye diseases than others not so engaged; in fact, statistics would seem to prove that the habitual exercise of the eye upon fine work tends to its development and to the preservation of its powers.

DIFFERENT GLASSES FOR DAY AND NIGHT USE.

The glasses first prescribed are usually worn only at night because the need for them is felt principally by artificial light. These suffice for a year or two, and then gradually the feeling grows on the person that the glasses are scarcely strong enough, which feeling is verified by a visit to the optometrist's, where a somewhat stronger pair are procured. At this time vision for small objects at hand begins to be a little indistinct, even in daytime, and soon the individual finds he is unable, at any time, to read without the assistance afforded by convex glasses. Under these circumstances, if the former night glasses are worn during the day, they render small letters clear and easily legible, even though they no longer sufficed for night use.

In the course of a year or two these glasses are scarcely sufficient, even for day use, and then they must be laid aside as no longer suitable for the person for whom they were prescribed, in the same manner as a suit of clothes is cast aside by the youth who has outgrown them. Then the night glasses are again brought into use during the day, and a new and stronger pair purchased for night use. These changes should not be made until the actual need for them is felt; and the fact is, that people generally err on the side of deferring the purchase of new and stronger glasses to the latest possible moment, instead of procuring them before the necessity for them is experienced.

GLASSES IN PRESBYOPIA.

The rule for presbyopia is that two pairs of glasses are called for—the stronger pair for night use and the weaker pair for day; and when the first become insufficient for their purpose, they are substituted for the day glasses, and a still stronger pair procured for use by artificial light. This is a very sensible rule, that looks well on paper, and sounds well theoretically; but, practically, the optometrist will have much difficulty in attempting to persuade his patients to follow its teachings.

There seem to be two chief reasons why this rule has not been generally adopted. In the first place, very few persons are willing to be bothered with two pairs of glasses, or, if they are willing to try it, they never have the right glasses at the right time. When they sit down in the evening by the fireside to read or sew, they can find only their day glasses, while the night glasses cannot be found, and nobody in the family knows what has become of them. And, similarly, when they want to use their eyes during the day, the night glasses are at hand, while the whereabouts of the day glasses cannot be discovered.

In the second place, and after all, since the use of gas (especially in the form of the Welsbach light) and electricity has become so common, the artificial light is so satisfactory that the need for stronger glasses is not felt nearly so much as in times past, when tallow candles were the chief source of artificial illumination.

DONDERS' ADVICE.

Our great master in accommodation and refraction says: "In general it should be observed that it is desirable to ascend but slowly in numbers; to use the first spectacles in the beginning only in the evening, and to keep these for day spectacles so soon as stronger glasses are required for the evening, and thus, every time that the stronger glasses are required, to continue using the former evening spectacles as day spectacles; finally, that while stronger glasses are necessary for reading, the weaker are often sufficient for writing and are to be preferred, since the person wearing them, being enabled to see at a greater distance, can avoid the bent position, which is so injurious to the eyes."

GLASSES PRESCRIBED ACCORDING TO AGE.

There has always been a popular notion among the laity, and it is still more or less prevalent, that glasses for the correction of presbyopia can be chosen according to the age of the individual, and that for each year of the presbyopic period there is a corresponding strength of glass. And even the old-time opticians shared in this feeling, and usually made the attempt (though oftentimes unsuccessfully) to prescribe the convex glasses on the basis of the patient's age, without making any further inquiries.

Now, if all eyes were of the same refraction, and at the same age began to lose in accommodative power in equal proportion, and the circumstances surrounding the use of the eyes in every individual were similar, then all eyes would begin to be presbyopic at the same age, and the adaptation of convex glasses for the correction of presbyopia would be reduced to the simple question of asking the age of the patient, and a table could readily be prepared that would be a trustworthy guide for examiner or patient in selecting glasses according to the rule referred to, which, under the circumstances, would be infallible.

But no two pairs of eyes seem to be exactly alike in their physical condition or in the manner in which they are brought into daily use; and hence the individual differences in the state of the refraction and the accommodation, at the specified periods of life, are too great for the preparation of a rule for the prescribing of glasses according to age, that can have any real value except approximately. Therefore, this method of fitting glasses cannot be relied upon, and should not be resorted to by the optometrist in his management of cases of presbyopia, to the exclusion of an individual examination in each case.

TABLES FOR PRESBYOPIA.

In persons with emmetropic eyes, in good bodily health, and with no symptoms of premature senility, and if the eyes are not subjected to any unusual strain, or used under unfavorable conditions, a table may be prepared which will approach the results obtained by a skilled examination in each individual case.

A common rule is to commence with + 1 D. at forty-five years of age, and add + 1 D. for every five years, as follows:

Age of patient	Glasses required.
45	+ 1 D.
50	+ 2 "
55	+ 3 "
60	+ 4 "
70	+ 5 "

Another table, more particular and more nearly correct, perhaps, has been figured out on the lines laid down by Donders. This commences at the age of forty-five with a + .50 lens, which, in most cases, suffices (instead of the + 1 D. called for in the above table):

Age of patient	Glasses required if emmetropic.
45	+ .50 D.
48	+ .75 "
50	+ 1 "
55	+ 1.50 "
58	+ 2 "
60	+ 2.50 "
62	+ 3 "
65	+ 4 "
70	+ 5.50 "
75	+ 6.50 "
78	+ 7.50 "
80	+ 9 "

While this table is not to be used on a basis on which to order the glasses, yet it can be taken as a guide-post pointing to the normal condition, and any marked departure therefrom would indicate some abnormality of refraction. If much stronger glasses are necessary at any particular age than the table indicates, hypermetropia is to be suspected. While, if the need of glasses is postponed much after the age of forty-five, and much weaker glasses suffice at any specified age than the table would indicate, myopia is most likely to be present.

PRESBYOPIA WHEN COMPLICATED.

It is the proper method, in all cases of presbyopia that apply for glasses only for reading, to ascertain the acuteness of vision and determine the condition of the refraction of the eye. As soon as the optometrist calls the attention of the patient to the card of test-letters hanging across the room, the almost invariable reply of the patient is, that their distant vision is all right, and that they do not need glasses to see off or across the room, but want them only for reading. This necessitates the optometrist telling his patient why the distant vision must be tested in order to ascertain the real refractive condition of the eye.

The cases of presbyopia that will require to be the most carefully fitted are those which are complicated with some existing error of refraction. Perhaps glasses may have been worn for the optical defect for many years, and as the person grows older, and gets into middle life, presbyopia begins to make its appearance and complicate the defective vision, and then the glasses will have to be changed to meet the altered conditions.

HYPERMETROPIA AND PRESBYOPIA.

As hypermetropia is the predominant error of refraction, so it will complicate many cases of presbyopia. Hypermetropia in many persons first shows itself as an early presbyopia; that is, the individual may not be aware that his eyes have any defect in their optical condition, because the hypermetropia exists in a latent form; but as age creeps on the latent defect gradually becomes manifest, and the condition of presbyopia is made to commence much earlier than it otherwise would in emmetropic eyes.

The optical student who has understandingly read the preceding pages will appreciate the reason for this; during his earlier years the patient was able to overcome the hypermetropia while the lens was soft and elastic, and without any appreciable effort; but as time goes on the refraction diminishes, and the near point recedes with him much earlier in life than with the emmetrope, and he will require a weak convex glass for reading long before he is forty years of age.

If hypermetropia is suspected as existing in any case in connection with the presbyopia, the eyes should be tested for it. In fact, in the routine examination of any case of presbyopia, it is the proper thing to determine the condition of the refraction, and to detect any departure from the emmetropic state. For, it may be repeated, in presbyopia, pure and simple, the refraction is normal and the distant vision is unimpaired. Just as soon as any error of refraction is detected in any supposed case of presbyopia, it ceases to be a case of presbyopia, and should be classed with that particular defect that is found to be present, which is then complicated with approaching old sight.

TESTING FOR HYPERMETROPIA.

If much stronger glasses are required at any particular age than the foregoing tables would indicate, the presence of hypermetropia is suspected. The diagnosis of hypermetropia depends upon the acceptance of a convex lens for distance. The patient is requested to name the letters on the test-card hanging twenty feet away; this determines his acuteness of vision, which, in some cases, is normal, although it is usually below the standard. Then a weak convex lens is placed before the eye, followed by stronger and stronger ones, and the strongest convex lens that is accepted will be the measure of the hypermetropia.

If the convex lenses improve the clearness of the letters, and raise the acuteness of vision, or if they do not blur the appearance of the letters, but allow them to be read equally as well as without the lenses, the presence of hypermetropia is proven. But, on the other hand, if all convex lenses blur the letters, and even the weakest is rejected, the optometrist may reasonably conclude that the patient has no hypermetropia, at least no manifest hypermetropia. It might be remarked in parenthesis that there is but little likelihood of the defect existing in a latent form, because at the presbyopic age latent hypermetropia becomes manifest and is no longer concealed by the weakened accommodation.

CORRECTION OF HYPERMETROPIA AND PRESBYOPIA.

If hypermetropia is found to be present, it must first be corrected by the proper neutralizing glasses, as indicated above; these glasses may, perhaps, even suffice for reading for a while, but sooner or later, in all cases, additional strength is required for reading.

The answer to the question as to whether the glasses that correct the hypermetropia are sufficiently strong for reading. will depend on the amount of available accommodation enjoyed by the patient, with the assistance of the glasses, or, in other words, on the position of the near point. If, with the glasses, the near point is still within eight inches, nothing more is needed for reading for the present.

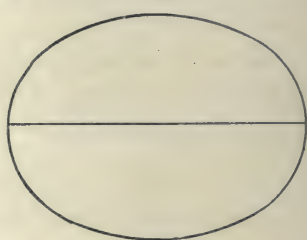
But if with the glasses the near point has receded to ten or twelve inches, the eyes are in need of additional assistance, and the number of the glasses required is obtained by the same calculation as in simple presbyopia.

For instance, if + 1 D. was the strongest lens accepted for distant vision, we would consider that lens as the measure of the hypermetropia. With this glass over the eyes the near point is measured and found to have receded to ten inches. Now, the glass representing the receded near point of ten inches is 4 D., and the glasses representing the near point as it should be (eight inches) is 5 D.; then the calculation is to subtract 4 D. from 5 D., which leaves 1 D. as the measure of the presbyopia over and above the hypermetropia.

This patient, therefore, has 1 D. of hypermetropia, and an additional 1 D. of presbyopia. The sum of these two glasses combined will give the actual amount of presbyopia, and will be the glasses needed for reading. Two pairs of glasses are, therefore, required—one for distance and constant wear, and another (and stronger) for reading.

In cases of hypermetropia as slight as this, the acuteness of vision is not usually much impaired, and the need of glasses is not felt for distant vision. In such a case the + 2 D. glasses are prescribed for reading, and the patient gets along very well until the next change of glasses is needed, which may not be for three or four years.

If, for any reason (asthenopia perhaps), it seems desirable to order glasses for distance, a pair of + 1 D. spectacles are given for that purpose, which are substituted by the + 2 D. when reading or close work is desired. Or, instead of removing the + 1 D. distance glasses when he wants to read, he may have another pair of + 1 D. lenses in an extra front frame, which he hooks over his distance glasses, and the sum of the two together affords him just the strength he needs for reading.



Or, if the patient doesn't want to go to even this much trouble, the glasses may be ordered "bifocal," in which the upper portion of the glass is that required for distant vision, while the lower segment represents the glass required for reading.

"Split glasses" were in use for many years as the best form of bifocal glasses obtainable; but recently they have been superseded by the new form, in which the size of the distance portion of the glass is increased at the expense of the reading part.

In some cases the reading power is obtained by cementing a small thin segment on the lower part of the distance glass; and in other cases the lower part of the distance glass is cut out and replaced by the proper reading lens.

MYOPIA WITH PRESBYOPIA.

Presbyopia also comes to those who are myopic; but in this case the myopia tends to neutralize the presbyopia and retards the recession of the near point, and hence the inconveniences of presbyopia are not experienced until much later in life. In cases of high degrees of myopia, where the far point lies at or nearer than eight inches, presbyopia can never occur.

We often hear of persons who have reached fifty-five or sixty years of age and are still able to read without glasses, and they are spoken of, and pointed out, as persons possessing wonderful sight; but the fact is, that the persons who are able to read at this age without glasses are usually myopic, and an examination of their acuteness of vision will soon determine it. If the myopia is not of high degree, they may have gone through life without being conscious of it, and are disposed to attribute their ability to read without glasses, after middle life, to the exceptional strength of their eyes.

In cases of myopia of 2 D. or 3 D., where, perhaps, the glasses have been worn constantly, as the person approaches the presbyopic period of life, he finds he can read better without his glasses, although he still needs them for distance. As he passes on into the fifties, he finds that reading is not so pleasant as formerly; in fact, he begins to feel the need of some assistance. In this case the myopia, by increasing the refraction of the eye, had kept the near point within eight inches, but now an examination will show that it has receded beyond this point. A weak convex lens that will restore the receded near point and enable the person to read comfortably at the usual distance, will be all that is required to relieve the presbyopic symptoms, while the same concave lenses may still be worn for distance.

In the higher grades of myopia (5 D. and over), presbyopia, strictly speaking, cannot occur in the sense that the near point cannot recede beyond eight inches; but such eyes are not excepted from the usual changes that accompany age; even in myopia the crystalline lens grows harder and denser, and the ciliary muscle (never very strong) grows weaker.

In youth, when the lens is elastic, the accommodation is sufficiently strong to allow the same glasses to be worn constantly for reading as well as for distance; but, on account of the inevitable senile changes, when the patient reaches forty years of age he is scarcely able to read with his glasses any more, nor would it be prudent for him to read without them. In this case we want the effect of a convex lens, which we can obtain by ordering a weaker concave glass for reading, which the patient will be able to use at the proper reading distance with comfort.

When a patient wearing — 8 D. glasses for distance reaches fifty years of age, his glasses will make the print so small and blurred that he will be unable to read. Now, according to the table, an emmetropic eye at this age has a presbyopia of 2 D., and if we place a + 2 D. lens before the — 8 D. glass, we have — 6 D. as the proper glasses to prescribe for this patient for reading.

But in many cases of myopia the accommodation is so feeble that the reading glasses calculated by this rule would be too strong; and, perhaps, the necessary glasses can be more accurately determined by the following method: We reduce the grade of the myopia just so much as to afford a convenient far point; for instance, a myopia of 3 D. has a far point of thirteen inches, which is a comfortable reading distance. If we prescribe — 5 D. glasses, we leave 3 D. of myopia uncorrected; and, therefore, a pair of — 5 D. glasses for reading would afford a far point of thirteen inches, and would, probably, prove more satisfactory than the — 6 D. glasses mentioned above.

The celebrated philosopher, Benjamin Franklin, was myopic, but not of a very high degree. He wore concave glasses for distance, and after he passed sixty years of age he wore convex glasses for reading. He wore the divided glasses, the upper half concave, the lower half convex. For this reason such glasses are often called Franklin lenses.

PRESBYOPIA WITH ASTIGMATISM.

In those cases of presbyopia where the refraction is complicated by astigmatism, there is sometimes difficulty in making a satisfactory adjustment. The rule here is to determine the refraction of the eye and correct the astigmatism, and then add to these cylindrical glasses suitable convex lenses, such as will make the vision clear and comfortable at the reading point.

If the astigmatism is slight in degree, it may sometimes be disregarded in making the presbyopic correction, and simple convex lenses prescribed with entire satisfaction. But if marked astigmatism is present it cannot be ignored, but must be included in the correction.

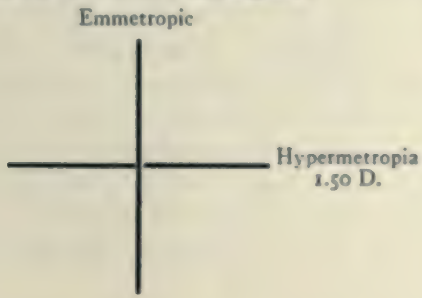
SIMPLE HYPERMETROPIC ASTIGMATISM.

The astigmatic patient who applies to the optometrist for glasses for reading (presbyopia), may wear cylindrical glasses, or, perhaps, may not. If the former, the optometrist can easily measure the glasses to ascertain what they are. If the latter, the method of examination which we have taught the optometrist to pursue will reveal the defect, and, at the same time, indicate the correcting lenses.

Suppose a patient comes with simple hypermetropic astigmatism, and the correcting lens (no matter whether previously worn or if just determined by the optometrist) is

+ 1.50 D. Cyl., axis 90°

In this case the refraction of the two chief meridians is indicated and illustrated by the following figure:



The vertical meridian is emmetropic, and the defective horizontal meridian is made so by the correcting cylinder. This måkes both meridians emmetropic and places the eye on the same plane as an emmetropic eye, and, therefore, subject to the same rules for the correction of presbyopia as in emmetropia.

The patient is forty-eight years of age, and the measurement of the near point (with the correcting cylinders before his eyes) shows it has receded to eleven inches. By following the rules given in the earlier pages of this chapter for measuring presbyopia and determining the glasses required to relieve it, we find this patient needs glasses of + 1.50 D. With these glasses placed in the trial-frame over the cylinders, the print is made clear and legible and reading becomes pleasant and comfortable, and the patient is satisfied this is just what he needs for reading.

The prescription would read as follows:

$$+ 1.50 \text{ D. S.} \supset + 1.50 \text{ D. Cyl., axis } 90°$$

This is a sphero-cylindrical lens, and must be ground to order for this patient.

SIMPLE MYOPIC ASTIGMATISM.

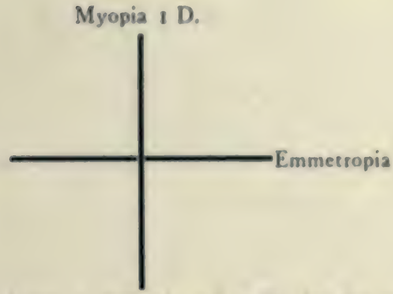
Another interesting class of cases, with which presbyopia may be complicated, is that of simple myopic astigmatism, in which the one meridian is myopic and the other meridian is emmetropic.

Now, if we examine each meridian separately, we will find that in the myopic meridian the patient will not need a convex glass for reading in the commencement of the presbyopic period, because the refraction in that meridian is the same as in a case of simple myopia, and, hence, is adapted for the divergent rays coming from a close point.

But in the meridian at right angles to this, which is emmetropic, reading is blurred and indistinct, and there is every evidence of the existence of presbyopia, and the patient will require the same strength of convex lens for reading as the wholly emmetropic person of the same age requires.

Perhaps these points can be made more clear by an illustration. Suppose we have a case of simple myopic astigmatism of 1 D., which might be expressed as follows:

$$V. = 20/40\text{; with } - 1 \text{ D. Cyl., axis } 180°\text{, } V. = 20/20$$



In this case we have a myopia of 1 D. in the vertical meridian, while the horizontal meridian is emmetropic. Now, a person with uncomplicated presbyopia, at this age, would require about a + 1 D. glass to enable him to read comfortably at the proper distance; and, as our imaginary patient is emmetropic in the horizontal meridian, so he would require a convex lens of 1 D. to correct this meridian; while the vertical meridian, being myopic to the extent of 1 D., would require no glass for close vision, as the necessary convexity in this meridian is supplied by the myopic astigmatism.

Hence we have to assist the refractive power of the horizontal meridian alone, which we can do by ordering

$$+ 1 \text{ C. axis } 90^\circ$$

for reading, while

$$- 1 \text{ C. axis } 180^\circ$$

may still be worn for distance.

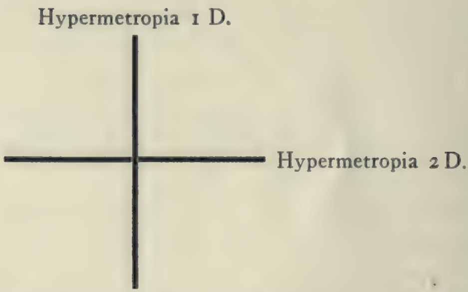
The correcting concave cylinders place the eye on the same plane as an emetropic eye, which, at this age, would require + 1 D. for its presbyopia. If, in like manner, we add + 1 D. to the glasses of this astigmatic presbyope, our prescription would be

$$+ 1 \text{ D. S.} \frown - 1 \text{ D. Cyl., axis } 180^\circ$$

This is practically the same prescription as the above, and the order for the glasses may be written either way, as each is correct.

COMPOUND HYPERMETROPIC ASTIGMATISM.

In cases of compound hypermetropic astigmatism that reach the presbyopic age, we follow the same rules of calculation, and add the presbyopic correction to the original sphero-cylinder, always remembering that the greater the degree of hypermetropia, the stronger will be the convex spherical element of the combination, modified by the age and bodily condition of the patient.



Suppose we have a patient who has been wearing the following correction for distance and for constant wear:

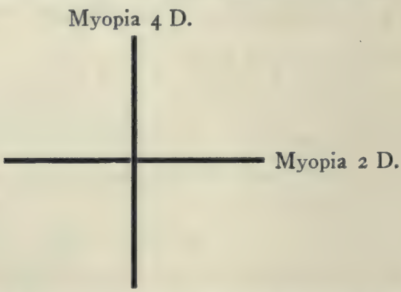
$$+ 1 \text{ D. S.} \supset + 1 \text{ D. Cyl., axis } 90°$$

as indicated by the above diagram. Such a patient will begin to feel the need of glasses, and show the symptoms of presbyopia, about the age of forty years, when an additional + 1 D. will be called for, for reading, and the prescription would be:

$$+ 2 \text{ D. S.} \supset + 1 \text{ D. Cyl., axis } 90°$$

COMPOUND MYOPIC ASTIGMATISM.

In this condition of refraction, the presbyopic correction must be subtracted from the concave spherical element of the combination, while the cylindrical element remains unchanged, and, hence, the greater the degree of myopia, the weaker will be the convex glass required, according to the age and general physical condition of the patient. The calculation in this case may seem more complicated than in the preceding case.



Suppose we have a patient who has ben wearing the following combination for constant use:

$$- 2 \text{ D. S.} \supset - 2 \text{ D. Cyl., axis } 180°$$

When this patient reaches forty years of age, these glasses will not seem so pleasant and satisfactory as formerly. This is due to the approach of the presbyopic changes, and the patient must have the benefit of a convex lens of about 1 D. We add it to the combination with the following result:

$$\begin{array}{l}
-\ 2\text{ D. S.} \bigcirc -\ 2\text{ D. Cyl., axis } 180^\circ \\
+\ 1\text{ D. S.} \\
\hline
-\ 1\text{ D. S.} \bigcirc -\ 2\text{ D. Cyl., axis } 180^\circ
\end{array}$$

These glasses will be a great improvement for a time; but after awhile they will no longer suffice, and the patient will need the effect of a + 2 D. lens; and then we have the following sum to work out:

$$\begin{array}{l}
-\ 2\text{ D. S.} \bigcirc -\ 2\text{ D. Cyl., axis } 180^\circ \\
+\ 2\text{ D. S.} \\
\hline
\qquad\qquad\quad -\ 2\text{ D. Cyl., axis } 180^\circ
\end{array}$$

Now the correcting lens for reading is a plain cylinder.

But the presbyopic changes are constantly progressing, and the glasses do not last forever, and, in the course of a few years, a lens of + 3 D. would ordinarily be called for, and must be added to the combination with the following result:

$$\begin{array}{l}
-\ 2\text{ D. S.} \bigcirc -\ 2\text{ D. Cyl., axis } 180^\circ \\
+\ 3\text{ D. S.} \\
\hline
+\ 1\text{ D. S.} \bigcirc -\ 2\text{ D. Cyl., axis } 180^\circ
\end{array}$$

And thus the varying changes in the dynamic refraction of the eye are met with corresponding changes in the spherical element of the correcting combination.

MIXED ASTIGMATISM.

Myopia 1 D.

Hypermetropia 1 D.

Suppose we have a patient with a mixed astigmatism, who has been wearing the following cross cylinders:

$$+ 1 \text{ D. Cyl., axis } 90^{\circ} \;|\overline{}\; - 1 \text{ D. Cyl., axis } 180^{\circ}$$

When this patient reaches forty-five years of age, he will complain that the reading is blurred and indistinct; or, perhaps, he will scarcely be able to read at all. If we place a + 1 D. lens over his spectacles, he says the print is made much more distinct, and he can read now with comfort. This gives us the following sum:

$$\begin{array}{l} + 1 \text{ D. Cyl., axis } 90^{\circ}, \bigcirc - 1 \text{ D. Cyl., axis } 180^{\circ} \\ + 1 \text{ D. S.} \\ \hline \end{array}$$

But we cannot add a spherical to, nor subtract it from, a cylinder; and, hence, the result of this sum is not so easy to ascertain.

When the case is analyzed, however, and the refraction of each meridian considered separately, the problem is much simplified, and may be stated as follows:

Horizontal Meridian + 1.	Vertical Meridian — 1.
+ 1.	+ 1.
Horizontal Meridian + 2.	Vertical Meridian 0.

The result of this sum is expressed by the following prescription:

$$+ 2 \text{ D. Cyl., axis } 90^{\circ}$$

The cross cylinder in this case may be transposed into a sphero-cylinder, and written in two different ways:

$$+ 1 \text{ D. S.} \bigcirc - 2 \text{ D. Cyl., axis } 180^{\circ}$$

or

$$- 1 \text{ D. S.} \bigcirc + 2 \text{ D. Cyl., axis } 90^{\circ}$$

Now, if we add + 1 D. S. to the first combination, the result is + 2 D. S. $\bigcirc$ — 2 D. Cyl., axis 180°, which can be reduced to + 2 D. Cyl., axis 90°, because the minus cylinder neutralizes the plus spherical in the vertical meridian.

If we add + 1 D. S. to the second combination, the + 1 will neutralize the — 1 and leave + 2 D. Cyl., axis 90°, as the result, which is the same in every case, even when the problem is differently worked out.

METHOD OF EXAMINATION.

The clinical investigation of any case of supposed presbyopia should commence, first of all, with a test of the static refraction of the eye, and a determination of the acuteness of vision. This will reveal the existence of any hypermetropia, myopia or astigmatism, and render possible the classification of the presbyopia, as to whether it is simple or complicated.

The methods in common use for the detection of these defects have already been described at considerable length in the previous chapter, and need not be repeated here. Suffice it to say, that in hypermetropia the measure of the defect must be added to the value of the glasses ordinarily required by a presbyopic emmetrope of the same age, while in myopia the degree of defect must be subtracted, in order to arrive at an approximate estimate of the glasses required for reading. In astigmatism the correcting cylinder must be combined with the requisite convex spherical lens.

Only in patients where the refraction is emmetropic and the acuteness of vision measures up to the normal standard, is the case to be considered one of simple and uncomplicated presbyopia, and to be measured and corrected according to the rules laid down for this condition.

TESTING NEAR VISION.

After the determination of the condition of the refraction (the tests for which are made at a distance of twenty feet), and not before, a trial should be made of the near vision, to ascertain the reading capacity and to measure the amplitude of accommodation. This will give the position of the receded near point, on the distance of which depends the degree of the presbyopia; while the principle involved in the correction of the disability is to supply a glass that will restore the receded near point to a convenient distance, and supplement the failing accommodation.

This confines the treatment of presbyopia to a palliation of the impaired condition of the sight. However, when suitable glasses are prescribed, the individual is enabled again to use his eyes freely for near work without fatigue. If the glasses are too weak, they fall short of affording the full measure of relief; while if they are too strong, they necessitate the holding of the book too close to the eyes, and thus impose extra work upon the convergence, and may give rise to symptoms of asthenopia.

GLASSES MUST BE CHANGED.

The need for a change of glasses from time to time will be felt in all cases of presbyopia, due to a steady and continued loss of accommodation. This need will be accompanied by the same symptoms that indicate the commencement of presbyopia, and it arises at intervals until the accommodation is entirely gone, when the patient may not require any further change of glasses for many years.

The frequency of these changes varies much in different individuals, depending on the innervation of the eye and the sensitiveness of the patient to slight inconveniences, as well as the nature of one's occupation, and the degree and accuracy of sight required. In general, they should be made as often as once in every two or three years; not oftener than every two years without exciting suspicion of the existence of some complication that endangers vision; nor longer than three years, else the eyes will be strained by reason of the glasses being of insufficient power.

The amount of change, or the difference between the old and the new lenses, will vary with the interval that has elapsed, and the rapidity of the failure of the accommodation. Each time such a change is to be made the new lenses must be chosen according to the same rules that determined the choice of the old ones, or according to the rules laid down for commencing presbyopia.

5 D. OF ACCOMMODATION NECESSARY FOR NEAR VISION.

The amount of available accommodation should not fall below 5 D., to the end that near vision may be pleasant and comfortable. As presbyopia steals on, and it begins to fall below this point, we supply the deficiency by placing a convex lens on the outside of the eye. Thus the accommodation steadily decreases and the convex lens as steadily increases, until, finally, there is an entire loss of accommodation, and we find a 5 D. lens supplying the necessary reading power.

This lens would always suffice thereafter if the dioptric system of the eye remained stationary. But the senile changes do not stop with an entire loss of accommodative power, but continue until they cause the eye to pass over into a condition of acquired hypermetropia, when the 5 D. lens will no longer suffice. Now a glass is called for, not only to take the place of the lost acommodation, but also to correct the supervening error of refraction.

AMBLYOPIA.

Amblyopia (which is an impairment of vision not due to refractive errors which can be corrected by glasses, but dependent upon organic disease which places it beyond the optometrist's help) sometimes exists in connection with presbyopia, and may even be mistaken for it, because the amblyopic patient, in like manner, cannot see very small objects distinctly, and sometimes, also, convex glasses improve his vision. But in simple presbyopia (uncomplicated with amblyopia) the patient enjoys the normal acuteness of vision and an unrestricted range of accommodation, which would be impossible in the presence of amblyopia. Besides, with the proper convex glasses the patient is able to read the No. 1 type as close as eight inches; but if he can read only the No. 3 or No. 4, and that with a conscious effort, or is obliged to hold the book at some unusual distance, we may reasonably infer that he is amblyopic.

GLASSES SHOULD NOT MAGNIFY TOO MUCH.

It should always be borne in mind that the object of the glasses prescribed for the relief of presbyopia is not to magnify the print, this being merely an incidental effect, but rather to add to the refractive power of the eye and assist the crystalline lens in focusing divergent rays of light upon the retina. Only so much assistance should be given as is really required, and it follows that anything more than this would be not only superfluous, but injurious.

The magnifying of the print produced by the convex glasses worn by the presbyope depends on two factors: First, the enlarging effect of the convex lens itself (this power being inherent in all convex lenses); and, secondly, the contrast with the appearance of the letters before the glasses were used, the print for some time previously having been diminishing in size, on account of the lessened refractive power being scarcely sufficient to bring it to a focus on the retina. Hence, when glasses are worn and the refraction increased, a clear and distinct image is formed, which contrasts strongly with the previous indistinct one.

PRESCRIBING GLASSES FOR PRESBYOPIA SHOULD NOT BE CARELESSLY DONE.

Although it seems to be a very simple and easy matter to adjust glasses for presbyopia, the truth is, mistakes are not uncommon, more so, perhaps, than in the correction of some of the other errors of refraction. If such is the case, the cause is to be found in the fact that presbyopia is not a well-defined departure from the normal form or structure (as are the various optical defects), but is rather an impairment of function of the crystalline lens and the ciliary muscle, the latter of which does not always enjoy the same degree of innervation, varying greatly at different times and under differing circumstances.

In youth the muscle possesses a normal tone, which is constant, as a rule; but there is a wide departure from this condition in presbyopia.

A patient who is apparently satisfied and pleased with his glasses one day, may return the next day with the complaint that they are entirely unsuitable. This is, perhaps, more often the case with women, because they do not seem to be able to interpret their sensations and express their feelings as accurately as men.

GIVE THE PATIENT A CHANCE TO EXPRESS HIS CHOICE.

The optometrist should not follow too closely any iron-bound rule in prescribing glasses for presbyopia. Sometimes a stronger glass, and sometimes a weaker one, will give more satisfaction than the one that seems to be indicated.

The effort should always be made to afford the patient as extended a range of accommodation as possible, by giving the glasses that allow the greatest distance between the near point and far point of distinct reading vision. This will operate in the direction of forbidding a glass that is too strong, because the stronger the glass the more restricted will be the range of accommodation.

This calls for the trial of several pairs of glasses, those slightly stronger and those a little weaker, in connection with the pair that seems to be indicated by the test that has been made. Then the patient should be allowed to express his preference for the pair of glasses that appear to him to be the most satisfactory. Not that the patient's choice should be necessarily determine the matter, but because his preference should be given some consideration in arriving at a final decision.

COMMON SENSE TO BE USED.

Sometimes the patient may be right and sometimes he may be wrong, but the optometrist, in the light of the knowledge gained by his examination, will be able to determine which it is. If your judgment sustains the patient's choice, it is a satisfaction to him to receive the glasses which he feels are suitable. But if otherwise, you must be the final arbiter, and the responsibility for the proper selection rests with you. We occasionally meet with people who cannot be made to say that they are satisfied, either because of natural perverseness, or because the case is not an uncomplicated one.

Even though our scientific tests indicate a certain number of glass, we must not too strongly force it upon a patient against his own judgment. There must be an admixture of common sense with science, if the prescribed glasses are to be a success, and if the scientific optometrist wishes to avoid shipwreck of his superior skill and knowledge. After trying several pairs of glasses, the patient sometimes becomes confused, or his eyes get tired, and it is impossible for him to tell which pair suits him best; then the optometrist dispels the clouds and prescribes the glasses indicated by his tests.

PURPOSE FOR WHICH THE GLASSES ARE INTENDED.

The question should always be asked for what purpose the glasses are intended; are they desired for reading alone, for reading and writing, or also for sewing and working, and, in the latter case, at what distance the work is performed, as the strength of the glasses will vary somewhat with the use to which they are to be placed.

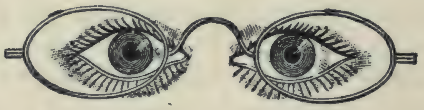
FITTING THE FRAME.

Great care should be taken in fitting the frame for reading glasses, to see that they are correctly centered and properly placed before the eyes, so that the eyes may look through the centers of the glasses, as otherwise the prismatic effect of the lens is unintentionally called into action.

The normal position for glasses is when they are correctly fitted over eyes that are looking at distant objects, the visual axes being parallel and corresponding exactly with the optical centers of the lenses, and they, in turn, with the geometrical

centers. For reading, the optical centers may be a trifle closer, a little lower, and the plane of the glasses may be inclined forward, so as to maintain it as nearly as possible at right angles to the line of vision.

A convex lens is thickest at the center, and may be looked upon as composed of an indefinite number of prisms with their



bases joined at the optical center. If the line of vision pass through this point, it is unaffected; but if it pass to either side, a prismatic effect becomes noticeable, the more marked the farther from the center the line passes.

If the frame is too wide, the pupils will look through the inner edge of the lenses, which will then act as prisms with

their bases outward. This increases the need for convergence, taxes the internal recti muscles, and strains the eyes. If the frames are too narrow, the line of vision will be directly through the outer edges of the lenses, with the effect produced of prisms with their bases inward. This assists the convergence and relieves the internal recti muscles; but, at the same time, disturbs the harmony that naturally exists between the accommodation and convergence, and in this way may be productive of symptoms of asthenopia. In case the frame should be improperly fitted, there would be much less discomfort to the eyes from frames that are too narrow than from frames that are too wide.

Oftentimes, when patients complain that their glasses are not satisfactory, the cause of the trouble may be found in the improper adjustment of the frame. This is an important matter, and if neglected may destroy the benefit of the most carefully adjusted lenses.

ORTHOSCOPIC LENSES.

In regard to the use of orthoscopic lenses (which have been described in this chapter) for the relief of presbyopia, the majority of persons wearing reading glasses will get along well enough without them. In the great number of cases, after the proper convex glasses are worn, the eyes become accustomed to the altered relation between the accommodation and convergence, and the use of the glasses is attended with no discomfort. But when the spherical convex glasses are uncomfortable and the eyes cannot get accustomed to their use for any length of time, and there is so much complaint from the patient that the optometrist is compelled to look for some remedy, then the prismatic glasses may be tried, and an effort made to bring the accommodation and convergence into harmony again. Sometimes, in such cases, a pair of orthoscopic spectacles will enable the person to read with the greatest comfort; but, of course, the book must be held just at the focal length of the prismatic combination, in which case there is an absence of all effort of either accommodation or convergence, and the removal of all the strain which previously attended and followed the use of ordinary spectacles.

On the other hand, it unfortunately happens, in some cases, that the orthoscopic glasses not only fail to afford relief, but even increase the discomfort that was formerly experienced. As these cases cannot be properly classified as simple presbyopia, the further consideration of their treatment will be postponed for the present and taken up again under the head of asthenopia.

There is one point that should be constantly borne in mind mind, and that is, a rapid increase in the presbyopia, requiring frequent changing of glasses for stronger ones, is the principal premonitory symptom of glaucoma; hence, if there is any suspicion of this disease, the optometrist must make careful examination for it according to the indications laid down in the earlier part of this chapter.

CLOSING REMARKS.

In closing this chapter on presbyopia, we will repeat a few of the important points. You should, in the first place, in all cases, ascertain the actual condition of the refraction. Find out if there be any existing error, either hypermetropia, myopia, or any of the various forms of astigmatism, and correct this carefully with a suitable glass or combination of glasses.

Then, with these glasses in the trial-frame placed before the eyes, you measure the range of accommodation to determine the near point and far point for reading easily the test-card that is held in the hand. If you find that the near point has receded from the eyes to a point beyond eight inches, you add to the glasses in the trial-frame a convex spherical glass of sufficient strength to bring the near point back to eight inches, and then calculate what the sum of the two glasses will be.

You can thus see that the hypermetrope will always require glasses stronger than the emmetrope to correct his presbyopia, while the myope will require glasses weaker in proportion as his degree of myopia is greater.

From what has already been said on these subjects, you will be able, in every case, to ascertain the refraction and the amplitude of accommodation, and the number of the glass which an eye requires for vision at any distance. You should take the precaution of giving the weaker numbers of convex glasses to those yet young and unaccustomed to wearing glasses, while you can give a half a dioptre more convex to an aged person, whose amplitude of accommodation is feeble and null.

You will sometimes meet with cases in which there may be amblyopia, and the patient is unable to read the fine type with any glass. With such persons, you must ascertain the smallest type which they can read, and, using that as your test, give them that convex glass which affords the best vision at the proper distance.

At other times the patient may be so illiterate that he cannot read; and we sometimes meet with such cases, even in this enlightened day. Here you must ascertain for what kind of work the glasses are desired, and prescribe that convex glass with which he can see to do that work most clearly and satisfactorily.

Perhaps some of our readers may think this chapter is too long, and that we have given too much time to the consideration of the accommodation and the proper correction of presbyopia. If so, our reply would be to call attention to the great importance of near vision in all civilized countries, and of the real and practical value of being able to take an exact account of the amplitude of the accommodation of the person examined, and thus to prescribe glasses scientifically.

TO THE OPTOMETRIST.

A large proportion of the persons you will be called upon to fit with glasses will be presbyopic, and, consequently, it behooves you to acquire a thorough knowledge and a clear understanding of this common defect, which, sooner or later, affects the eyes of every individual.

If you are able to fit presbyopia scientifically and satisfactorily, you will speedily gain an enviable reputation and lay the foundation of a growing optical business that will attract an increasing class of patients suffering from the more complicated optical defects. It is important for you to understand the changes that take place in the eye with the advance of age, and especially the changes in the lens and ciliary muscle which constitute the condition of presbyopia, with its accompanying deficiency of sight; and then your knowledge of the previous chapters will indicate the remedy and elucidate the scientific principles involved in the adjustment of the lenses required.

Presbyopia may seem like a simple defect that requires but little care in its correction; but whatever is worth doing at all is worth doing well. Remember, little things count, and a reputation can be made or marred by the manner in which even the simplest duty is performed.

APPENDIX.

Optical Symbols and Abbreviations.

Ac. .... Accommodation
Aet. .... Age.
Am. .... Ametropia.
An. .... Anisometropia.
As. .... Astigmatism.
Asth. .... Asthenopia.
Ax. .... Axis.
Cc. or — (minus) .... Concave.
Ce. .... Centigrade.
Cm. .... Centimeter.
Cx. or + (plus) .... Convex.
Cyl. .... Cylinder.
D. .... Dioptre.
D. Cc. .... Double Concave.
D. Cx. .... Double Convex.
D. T. .... Distance Test.
E. or Em. .... Emmetropia.
H. or Hy. .... Hypermetropia.
In. .... Inches.
L. or L. E. .... Left Eye.
M. or My. .... Myopia.
Mm. .... Millimeter.
N. .... Nasal.
Nv. .... Naked Vision.
O. D. (Oculus Dexter) .... Right Eye.
O. S. (Oculus Sinister) ... Left Eye.
O. U. (Oculi Unati) ...... Both Eyes.
P. or Pb. .... Presbyopia.
P. Cc. .... Periscopic Concave.
P. Cx. .... Periscopic Convex.
P. D. .... Inter-Pupillary Distance.

Pl.	Plano.
p. p. (Punctum Proximum)	Near Point.
p. r. (Punctum Remotum)	Far Point.
Pr.	Prism.
R. or R. E.	Right Eye.
R. T.	Reading Test.
Rx.	Prescription.
Sb.	Strabismus.
S. or Sph.	Spherical.
T.	Temporal.
Ty.	Type.
V.	Vision.
Va.	Visual Acuteness.
W. P.	Working Point.
+	Plus—Convex.
—	Minus—Concave.
⊂ (combination sign)	Combined with.
L.	At Right Angles.
°	Degree.
△	Prism-Dioptre.
′	Foot and Minute.
″	Inch and Second.
‴	Line, the twelfth part of an inch.
=	Equal to.
∞	Infinity, 20 feet or farther.

Glossary of Optical Terms.

Abduction........Movement of the eyeball outward.
Aberration........Wandering from normal.
Accommodation...Adjusting of the eye for near vision.
Achromatic.......Without color.
Achromatopsia....Color blindness.
Adduction........Movement of the eyeball inward.
Albinism..........Abnormal deficiency of pigment in iris and choroid.
Amaurosis........Partial or total loss of sight.
Amblyopia........Impairment or loss of vision without any apparent local cause or anomaly to account for it. Defective sensibility of the retina.
Amblyopia, Subdivisions of:
- Congenital...Existing from birth.
- Exanopsia...Loss of sight from continued disuse of the eye.
- Hemeralopia.Night blindness, due to blood degeneration.
- Hysterical...Effect of nervous reflex. A sympathetic condition.
- Nyctalopia..Day blindness, due to same cause as hemeralopia.
- Toxic........Due to poison absorbed into the system, as nicotine, alcohol, etc.
- Traumatic...Produced by a blow.

Ametropia........The condition when parallel rays of light will not focus in the eye. Opposite of emmetropia or normal vision.

Amplitude (as applied to accommodation)......Power or extent.
Anæsthesia of the Retina.........Insensibility of the retina.
Aniridia..........Absence of the iris.
Anisometropia....The condition when each eye has different refracting power, necessitating two different lenses for correction.
Anophthalmia.....Absence of eyes.
Anopsia..........Disuse of the eyes.
Aphakia..........The condition when the crystalline lens is removed, as after operation for cataract.
Aplanatic.........Without aberration.
Arcus senilis......Ring of corneal opacity in aged.
Asthenopia.......Weak sight due to weakness of the muscles controlling the eye.
Astigmatism......The condition when, by malformation of the cornea or of the crystalline lens, or other cause, the rays of light from a point will not focus at a point after passing through the dioptric media.
Biconcave........Double concave.
Bifocal...........Double focus.
Binocular.........Pertaining to both eyes.
Blepharitis........Inflammation of edges of eyelids.
Blind Spot........Entrance of optic nerve on retina.
Brachymetropia...Another term for myopia.
Canthus..........Angle of the eye.
Caruncle..........Small fleshy growth.
Cataract..........Opacity of crystalline lens.
Catoptrics........Laws of reflection of light.
Centrad..........Toward the center; unit of measurement for prisms.
Chalazion.........A cyst of the eyelid.
Chemosis.........Swelling of the conjunctiva.
Choroiditis........Inflammation of the choroid.
Chromatism......Coloration.
Cilia.............The eyelashes.

Ciliary............Pertaining to the cilia.
Concentric........Having a common center.
Concomitant......Accompanying.
Conjugate........Joined together.
Convergence......Turning to a point.
Coördination.....Harmonious action.
Cortical..........Pertaining to outer layer.
Coquille..........A shell.
Cyclitis...........Inflammation of ciliary body.
Cycloplegia.......Paralysis of ciliary muscle.
Dacryocystitis....Inflammation of lachrymal sac and duct.
Day-Blindness....Impairment of vision on bright days.
Decenter.........From the center.
Depilation........Plucking out a hair.
Dilation..........Expansion or widening.
Diopter...........Unit of measurement.
Dioptric..........Pertaining to the diopter.
Dioptrics.........Science of refraction by transparent media.
Diplopia..........Double vision.
Disk.............A circular plate; the papilla.
Divergence........To turn from.
Ecchymosis......Extravasation of blood into tissues.
Emmetropia......Normal vision.
Entoptic..........Within the eye.
Entropion........Inversion of margin of lids.
Enucleation.......Removal of eyeball.
Epiphora.........An undue secretion of tears.
Esophoria.........Deviation of visual line inward.
Exophoria........Deviation of visual line outward.
Exophthalmos....Protrusion of eyeballs.
Far Point.........Greatest reading distance.
Focus............Meeting point of refracted rays.
Fovea............Yellow spot.
Fundus...........Bottom of the eye.
Glaucoma........A disease of the eye characterized by hardening of the globe.
Granular Lids....An aggravated form of conjunctivitis.
Hemeralopia......Inability to see at night.
Hemianopsia.....The loss of vision in one-half the field.

Heterophoria.....Abnormal tending of vision lines, due to want of balance or coördination of ocular muscles.

Heterophoria, Subdivisions of:

- Esophoria........Tending of the visual lines inward.
- Exophoria.......Tending outward.
- Hyperphoria.....Tending of the visual line of either eye above the other.
- Hyperesophoria..Tending up and inward.
- Hyperexophoria..Tending up and outward.

Heterotropia......A deviation or squint.

Heterotropia, Subdivisions of:

- Esotropia........Convergent squint. Turning in.
- Exotropia........Divergent squint. Turning out.
- Hypertropia......The condition when one eye deviates above the other.
- Hyperesotropia...Deviation up and in.
- Hyperexotropia..Deviation up and out.

Homocentric......Having a common center.

Hordeolum.......A stye.

Horopter..........Boundary of vision.

Hydrophthalmia..Increase of fluids of eye.

Hyperæsthesia....Oversensitiveness of the retina.

Hypermetropia....Far-sightedness.

Hypopyon........Pus in anterior chamber.

Insufficiency......Incapacity of normal action within the eye.

Intraocular.......Within the eye.

Intraorbital.......Within the orbit.

Iridectomy........Cutting part of iris.

Iritis.............Inflammation of the iris.

Keratoscope......An instrument to measure the cornea.

Keratitis..........Inflammation of cornea.

Keratocele........Hernia of cornea.
Keratoconus......Protrusion of cornea.
Lachrymation.....Excessive secretion of tears.
Leucoma.........Opacity of cornea.
Macula Lutea.....Yellow spot.
Megalopsia.......Seeing objects larger than normal.
Meibomian.......The glands of eyelids.
Meniscus........Crescent-shaped.
Metamorphopsia..Seeing objects distorted.
Meter-Angle......Angle of visual axis for one meter distance.
Micropsia.........Seeing objects smaller than normal.
Monocular........Belonging to one eye.
Muscæ Volitantes..Floating specks or imperfections in field of vision, due to shadow of vitreous cells.
Mydriasis........Unnatural dilatation of the pupil.
Mydriatic.........A drug that dilates the pupil.
Myopia...........Near-sightedness.
Myosis...........Unnatural contraction of the pupil.
Myotic...........A drug that contracts the pupil.
Nebula...........Opacity of cornea.
Neuritis..........Inflammation of optic nerve.
Nictitation........Excessive winking.
Night-Blindness...A form of retinitis.
Nyctalopia........Day-blindness.
Nystagmus.......Oscillations of eyeball.
Ocular............Pertaining to the eye.
Oculomotor.......The third cranial nerve.
Ophthalmia.......Inflammation of the eye.
Ophthalmic.......Belonging to the eye.
Ophthaldynameter An instrument to measure accommodation.
Ophthalmology....Science of the anatomy, physiology and diseases of the eye.
Ophthalmometer..Instrument to measure corneal curvature.
Ophthalmoplegia..Paralysis of ocular muscles.
Ophthalmoscope...Instrument to examine interior of eye.
Optic Axis........Imaginary line through center of cornea and lens.

Optic Disk........Entrance of optic nerve.
Optics............Science of light and vision.
Optometer........Instrument to measure refraction of eye.
Orbit.............Bony cavity for eyeball.
Orthophoria.......Coördination of the visual lines of the eyes.
Perfect muscular equilibrium in both eyes.
Opposite of heterophoria.
Orthotropia.......Normal as relates to squint. Opposite of heterotropia.
Palpebral.........Pertaining to eyelids.
Pannus...........Vascularization and opacity of cornea.
Panophthalmitis...General inflammation of eyeball.
Papilla...........The optic disk.
Papillitis..........Inflammation of optic disk.
Perimeter.........An instrument for measuring field of vision.
Periscopic........To look around.
Phosphenes.......Subjective light sensations caused by pressure on eyeballs.
Photometer.......An instrument for measuring intensity of light.
Photophobia......Dread or intolerance of light.
Pink-Eye.........Conjunctivitis.
Polyopia..........Multiple vision.
Presbyopia........Decreased power of accommodation, somewhat vaguely called old sight.
Prismoptometer...An instrument for estimating ametropia.
Pterygium........Thickening of conjunctiva at inner canthus.
Ptosis............Inability to lift the upper eyelid.
Pupilloscopy......The shadow test.
Pupillometer......Instrument for measuring the pupil.
Reflection.........Throwing back light.
Refraction........Deviation of light.
Retinitis..........Inflammation of the retina.
Retinoscopy......A method of measuring ametropia.
Scleritis..........Inflammation of the sclerotic.
Scotoma..........A dark spot in the visual field.

Skiascopy.........The shadow test.
Snow-blindness....Partial blindness from reflection of snow.
Spectroscope......An instrument for decomposing light.
Squint............Deviation of one eye.
Staphyloma.......Protrusion.
Stenopaic.........Having a narrow opening.
Strabismus ....Squinting of the eyes.
Stye..............A small boil in eyelid.
Subjective........Pertaining to oneself.
Supraorbital......Above the orbit.
Symblepharon....Adhesion of lid to eyeball.
Synechia..........Adhesion of iris to crystalline lens.
Tarsal............Belonging to the eyelid.
Tenotomy........Division of ocular muscle.
Tension of Eye....Term applied to hardness of eyeball.
Trachoma........Granular lids.
Trichiasis.........Inversion of eyelashes.
Uvea.............Choroid, ciliary body and iris as a whole.
Yellow Spot.......Point of retina possessing most acute vision.

INDEX