CENTRAL SCIENTIFIC COMPANY

OPERATING INSTRUCTIONS

Ingersoll Eye Model
No. 87660

1. Introduction

The Ingersoll Eye Model (87660) is a device for demonstrating the optical principles of the human eye. In particular, the eye model helps the student understand the nature of normal vision, farsightedness and nearsightedness, astigmatism, compound visual defects, cataracts, and other ocular or optical phenomena.

The eye model set contains the following components:

- the eye model
- a set of lenses
- a diaphragm
- an optical object box

2. Theory

2A. The Eye as an Optical Instrument

The human eye is a unique and versatile optical instrument. Most of its remarkable properties are concerned with the subjective mechanism of vision, which is a physiological and psychological problem having to do with sensory impressions. A primary and essential condition for vision is the formation of an image that stimulates the nerve centers in a pattern which results in the sensation of sight. Optics is concerned with the purely objective matter of image formation.

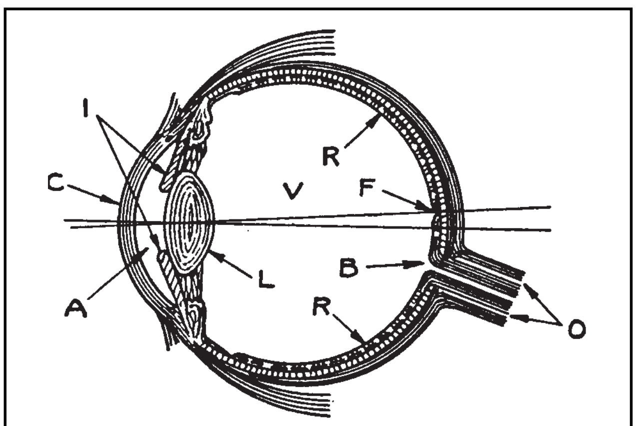

Figure 1 Diagram of the human eye. R — Retina, I — Iris, C — Cornea, V — Vitreous Humor, F — Fovea Centralis, B — Blind Spot, A —Aqueous Humor, L — Crystalline Lens, O — Optic Nerve.

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The structure of the eye is complex and admirably adapted to its functions. Figure 1 represents the principal parts of the eye and their relationships to image formation. Like a photographic camera, the eye consists of a dark chamber provided with an aperture and lens system on one side and with a light sensitive surface on the opposite side. In the eye the dark chamber is roughly spherical in shape and is filled with a transparent jelly-like substance known as the *vitreous humor*. The lens is a compound lens, in reality a doublet, consisting of a biconvex rear component and a convex meniscus front component. The crystalline lens, which forms the rear component of the couplet, is composed of a semi-plastic material with a refractive index of about 1.45. The lensticular space in front of the crystalline lens is filled with a watery liquid known as the *aqueous humor*, and is covered by a thin transparent shell called the *cornea* (in reality a continuation of the outer covering of the eye). Thus, the front component of the compound lens is a liquid meniscus having a refractive index of about 1.34. Between the two components is the *iris*, a colored, opaque curtain with a hole in the center called the *pupil*. The aperture (diameter of the pupil) is controlled by muscular reflexes, thereby automatically regulating the amount of light entering the eye.

The *retina*, upon which the image is produced, is a light sensitive surface on the inner lining of the back wall of the dark chamber. The sensory system of the eye is a network of *rods* and *cones* in the retina from which millions of nerve fibers lead to the *optic nerve*. The stimulation of the nerve endings in a pattern corresponding to the retinal image is the result of a complicated photochemical reaction, the precise nature of which is not thoroughly understood. At the place where the optic nerve leaves the eye there is an insensitive region on the retina called the *blind spot*. The region of greatest sensitivity is the *fovea centralis*, a region about 0.3mm in diameter near the center of the retina. As the eye scans an object it rotates in its socket so as to bring successive parts of the image on the *fovea centralis*. Thus, although the eye is able, by rotating, to cover a broad field of view and, when stationary, to receive visual impressions over a fairly wide angle, the angle of acute vision with the eye in a fixed position is small.

One of the most remarkable properties of the eye is its adaptability to stimuli of widely varying degrees of intensity. This is due principally to the existence of substance called "visual purple" found in the rods. The sensitivity of the retina increases with the concentration of visual purple, which increases in the absence of light stimulus. The effect of light is to bleach the visual purple, reducing its concentration and lowering the sensitivity of the retina. Thus the eye behaves somewhat like a camera provided with a film of variable sensitivity, the speed being inversely proportional to the brightness of the image.

Focusing, or accommodation for different object distances, is accomplished not by altering the image distance as in the camera, but by changing the focal length of the lens system. Around the periphery of the crystalline lens is an annular muscle called the *ciliary muscle*, the function of which is to control the curvature of the lens surfaces. In its relaxed condition, the lens of a normal eye is adapted to distant objects. Adaptation for near objects is accomplished by reflex contraction of the ciliary muscle which squeezes the lens at its periphery and causes it to bulge at the center, thereby shortening the focal length of the lens.

As the object is brought nearer to the eye the size of the retinal image is increased, thus increasing the amount of detail that can be observed. However, in the average eye, the curvature of the crystalline lens cannot be adapted to object distances less than about 25cm. The average minimum object distance is called the *distance of distinct vision*. A magnifier, or reading lens, merely supplements the adaptability of the eye and permits the object to be brought nearer, thereby producing a large and sharply defined retinal image. The image on the retina is, of course, inverted, but the correlation established by experience between the optical stimuli and the sensory impressions is such that inverted retinal images are associated with erect objects.

An important aspect of vision is the ability to judge distance, an aptitude which is responsible for the perception of relief in objects. The sensation of depth is due chiefly to the fact that we have two eyes. Two phenomena of binocular vision are responsible for the perception of relief, namely:

(1) *parallax*, i.e., a departure from parallelism in the lines of sight for the two eyes, thus necessitating a muscular effort in converging the optic axes upon a common point

(2) the *stereoscopic effect*, i.e., the formation of two retinal images from different view points, the images differing slightly in perspective.

In the case of distant objects both effects become negligible.

2B. Visual Defects and their Corrections

Farsightedness and Nearsightedness: Sometimes the focal length of the lens system is too great for the retinal distance, causing the image of a near-by object to be formed back of the retina. In this case only distant objects are imaged exactly on the retina. A person affected with farsightedness or *hpermetropia* is under a constant eye strain when reading unless the book is held at arm's length. A form of hypermetropia called *presbyopia*, or old-sightedness, has a tendency to develop with age owing to a gradual increase in the rigidity of the crystalline lens, rendering it less adaptable to short object distances. Farsightedness is corrected by supplementing the eye lens with a convergent, or positive, spectacle lens. The situation is represented diagrammatically in Figure 2.

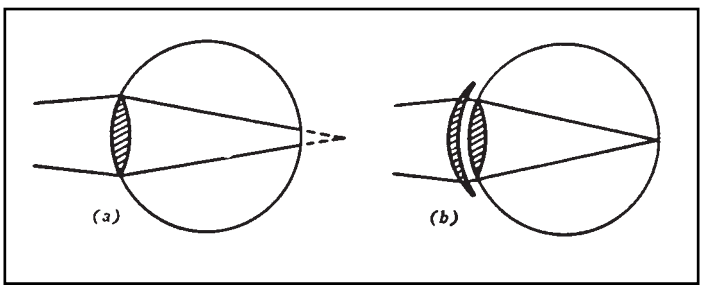

Figure 2 Farsightedness (a) uncorrected (b) corrected.

Nearsightedness, or *myopia*, is the result of a focal length too short (curvature too great) for the retinal distance, causing the image to be formed in front of the retina. Divergent, or negative, spectacle lenses are used to correct myopia as shown in Figure 3.

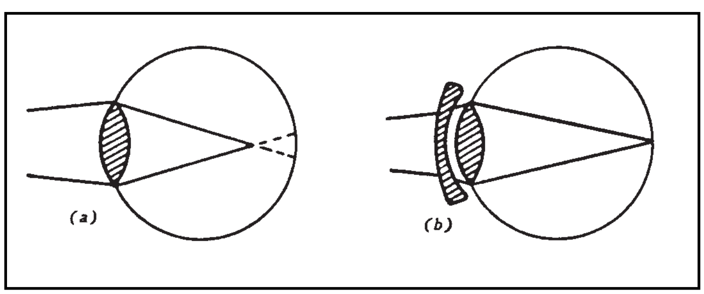

Figure 3 Nearsightedness (a) uncorrected (b) corrected.

Astigmatism: Astigmatism is a defect of optical instruments the effect of which is to image a point source of light as a short straight line instead of as a point. It results from a lack of symmetry of the optical system about the line of sight. In the case of the eye, astigmatism results from a lack of symmetry of the lens system about its axis, i.e., a departure from sphericity in some of the refracting surfaces.

The result is that the image is not formed sharply anywhere, but there are two positions of best definition at one of which only lines in a certain direction are sharply defined and at the other position only lines at right angles to that direction. An astigmatic lens, therefore, has two unequal focal lengths for lines at right angles to each other. The difference between these focal lengths is called the *astigmatic difference*. Ocular astigmatism and its correction are illustrated in Figure 4 in which **L** represents a rectangular section cut out of the center of a non-symmetric plano-convex lens.

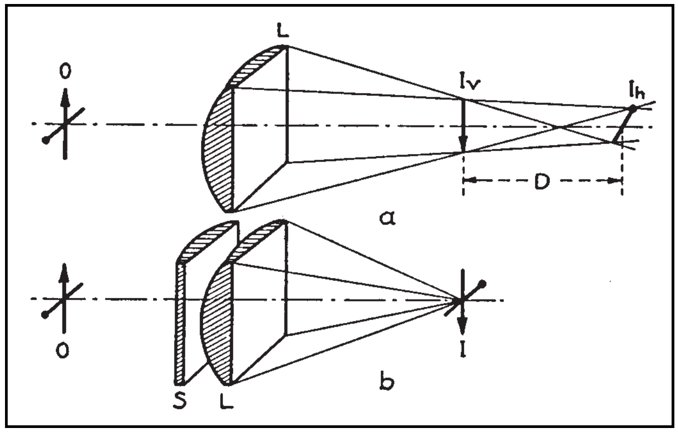

Figure 4 Astigmatism (a) uncorrected (b) corrected.

Since the curvature in the vertical plane is greater than in the horizontal plane, vertical lines in the object will be imaged at $\mathbf{I_v}$ closer to the lens than the images of horizontal lines $\mathbf{I_h}$. The astigmatic difference is represented by **D**. The corrections consists in the use of a cylindrical spectacle lens **S** with no curvature in one plane and sufficient curvature in the other to make up for the deficiency in the curvature of **L**. The combination is then the equivalent of a single spherical lens. If a negative spectacle lens were used having its curvature in the vertical plane, the corrected image would be at $\mathbf{I_h}$. An astigmatic eye looking at a design such as Figure 5 will see one set of parallel lines more distinctly than any other set.

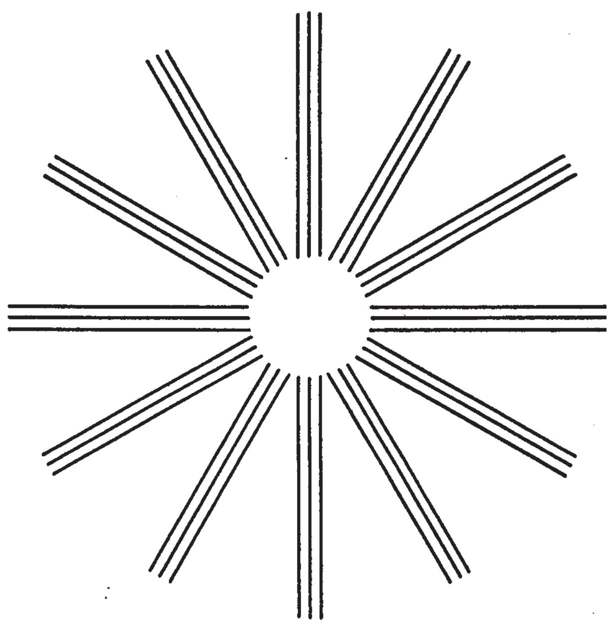

Figure 5 Test chart for astigmatism.

A student who wears glasses for the correction of astigmatism will find it instructive to examine Figure 5 with and without their glasses, and to observe the effect of rotating the lenses before their eyes.

Spectacle Lenses: The lenses used in a spectacles may be classified roughly as follows: Spherical lenses to compensate for far-and nearsightedness, cylindrical lenses for the correction of astigmatism, and non-spherical lenses designed to correct simultaneously for more than one defect.

All lenses are either *convergent* or *divergent*. A convergent (or positive) lens is one which brings the rays from a distant object to a focus, forming a *real image* back of the lens. A divergent (or negative) lens, on the other hand, so directs the rays that they seem to come from a nearby point (*virtual image*) in front of the lens. Convergent lenses are thicker in the center than at the periphery, while the opposite is true of divergent lenses. The focal length of a lens is defined as the distance from the lens to the image of a distant object; it is considered positive for a convergent lens and negative for a divergent lens. The *power*, or *dioptry*, of a lens is an index of its ability to bend rays of light; it is measured by the reciprocal of its focal length. The common unit of optical power is the *diopter*, the power of a lens in diopters being the reciprocal of its focal length in meters. Thus, it follows that the diopter is the power of a lens in diopters being the reciprocal of its focal length in meters. Thus, it follows that the diopter is the power of a lens whose focal length is 1 meter. The power of a combination of lenses used *close together* is the sum of their individual powers. Thus, a convergent lens of +1.5 diopters and a divergent lens of -2.0 diopters is the equivalent of a single divergent lens of -0.5 diopters (2 meters focal length). It is possible to tell a good deal about the nature of a person's visual defect by an examination of his spectacles. If a bright object such as a lamp is viewed through each lens in turn, the movement of the image resulting from a movement of the lens reveals the type of lens and hence the defect it is designed to correct. If rotation of the lens about the line of sight produces no effect, the lenses are spherical. If a lateral displacement of the lens causes an opposite displacement of the image, the lens is positive; if the lens and the image move in the same direction, it is negative. If rotation produces a deformation of the image, the lens is non-spherical and astigmatism is indicated. A further check upon this may be made by comparing the effects of vertical and horizontal displacements of the lens. If no movement of the image results from one of the displacements, the lens is a cylindrical one correcting only for astigmatism. If the two displacements of the lens produce unequal displacements of the image, the lens has some curvature in both planes indicating a compound correction. It is instructive to study these movements and to attempt to correlate them with the curvatures of the eye lens.

The principal image-forming properties of the eye are to be demonstrated in this experiment. Properties related to the sensory system cannot, of course, be demonstrated with a model. It is perhaps worthwhile, however, to mention a few of them in this brief outline. One of the most important limitations of the eye is its *resolving power*, by which is meant its ability to distinguish detail. At a viewing distance of 25cm the average normal eye is just able to distinguish two dots 0.25mm apart. At a greater distance the two dots would appear to the eye as one. Generally speaking, if two points subtend an angle at the eye of less than 3.6 minutes of arc, they cannot be resolved. The student will find it interesting to check this roughly by observing the greatest distance at which they can resolve the parallel lines of Figure 5.

Another important property of the eye is *persistence of vision* which is the continuance of the sensation after the stimulus is removed. This phenomenon is responsible for the illusion of continuous movement in motion pictures.

One of the most important characteristics of vision is the sensation of color, the mechanism of which is not thoroughly understood.

The interested student should consult the following references which deal with the various aspects of vision not dealt with in this experiment:

Howell, *A Textbook of Physiology*, W. B. Saunders Co., 1928
Martin, *The Human Body*, Henry Holt, 1930
Helmholtz, *Physiological Optics*, O.S.A., 1924-25.

3. Description

3A. The Eye Model

The eye model consists of a metal tank shaped roughly like a horizontal section of the eyeball. It is about 18cm long at its longest point, about 16.5cm wide at its widest, and 11.5cm high. A window in one side of the tank is covered with a meniscus lens, which serves as the cornea. When the tank is filled with water, it represents the eyeball and its aqueous and vitreous humors.

Supports are provided in front of and behind the meniscus lens for insertion of other lenses. behind the meniscus lens, you can insert the diaphragm from the optical lens set as well as the No. 2 lens from the same set, which can be used to mark the boundary between the "humors."

In front of the meniscus lens, you can insert various lenses from the optical lens set. The lenses in this set are of the kind used to correct defects of vision.

The retina is represented by a circular white area on a removable curved screen which fits into the tank. The screen is secured in place by sliding its ends into grooves provided on the tank's inside walls. There are three pairs of grooves, so you can place the screen in different positions. The "blind spot" is represented by a black spot on the "retina."

3B. Optical Lenses (87666-01)

A set of six different lenses, the kinds used by opticians in ascertaining defects of the eye, is supplied with each eye model. All the lenses are 38mm in diameter. Each lens is mounted in a metal holder, with the focal length (in diopters) stamped on its handle.

Lens No.	Type	Focal Length in Diopters
1	Plano-Convex	+7.00
2	Double Convex	+20.00
3	Spherical Convex	+2.00
4	Spherical Concave	-1.75
5	Cylindrical Concave	-5.50
6	Cylindrical Convex	+1.75

3C. Optical Object Box

This metal box, 10 x 10 x 16cm, contains an incandescent bulb and has a special ground glass and cutout screen at one end. The 40-watt bulb runs off ordinary line current, and the apparatus has a three-wire grounded cord and an on-off switch.

In the open end of the box is a piece of ground glass and cutout screen at one end. The 40-watt bulb runs off ordinary line current, and the apparatus has a three-wire grounded cord and an on-off switch.

In the open end of the box is a piece of ground glass, for diffusing light, and a metal square with a special cutout design, a radiating shape of eight slots. The slot at the top of the design ends in an arrowhead shape. The slot 90° to one side of the arrowhead ends in a circle. All the other slots have plain ends. By noting the position of the arrowhead and the circle, the student can tell whether the image of the design is seen right-side-up or upside-down, and whether it has been reversed left-to-right.

Place the optical object box so the center of the cutout design is 75mm above the top of the table on which the eye model rests.

Caution: The optical object box will become hot after it has been in use for a while because the incandescent bulb generates heat. Don't touch the box when it is hot — use the handle instead — and be sure not to block the ventilation slots on either side of the box.

The bottom of the box is drilled and tapped for a support rod (such as our Threaded 1 x 15cm Aluminum Rod with Shoulder, 72165-01). If you want to use the object box in other optical experiments on an optical bench such as our Advanced Lathe-Bed Optical Bench (85801), insert the support rod into an optical-bench carriage such as our Hinged Carriage (85802).

4. Procedure

Fill the tank with water to within about 2cm of the top. Place the retina in the normal (middle) position and insert lens No. 1 in the septum.

In performing the following seven experiments the student should include in his report a full description of the procedures followed. Since many of the observations have to do with the appearance of the image, this should be described. When quantitative measurements of object- and image-distances or object- and image-sizes are made, these should be recorded. The report should contain drawings illustrating the principles demonstrated.

4A. Accommodation

Face the "eye" toward a window or other large, well-illuminated object and note the characteristics of the image on the retina. Determine approximately the relative size of the image as compared to the object. Representing the sensitive surface of the retina by the white disk, determine the approximate total angle covered. If the fovea centralis is represented by a circle of 1cm radius in the center of the retina what is the angle of distinct vision? Scan the subject by rotating the eye and observe the effect of the blind spot on portions of the image. The student may demonstrate the existence of the blind spot in their eye by making a black dot in the middle of a sheet of paper and looking with one eye at the opposite edge of the paper. As the distance between the paper and the eye is changed, a position will be found where the dot cannot be seen.

Place the illuminated object box about 35cm (distance of "distinct vision" for the model eye) in front of the model and note the blurred appearance of the image. "Focus" the eye by replacing the crystalline lens with lens No. 2

4B. Farsightedness and Nearsightedness

Keeping the object distance the same, move the retina to the forward position $\mathbf{R_h}$ illustrating hypermetropia. Adjust the position of the object until the image is sharp. Select the proper spectacle lens from Nos. 3 and 4, mount it in front of the eye, and observe the effect on the image when the object is at the normal viewing distance of 35cm. Replace the retina in the normal position and note the nature of the image. This illustrates what happens when a person with normal vision puts on the spectacles of a far-sighted person.

Remove the spectacle lens and shift the retina to the rear position $\mathbf{R_m}$, producing myopia. find the best viewing distance as before. Correct the myopia by applying the proper spectacle lens.

4C. Pupil Size
With a normal or a corrected eye, insert the diaphragm immediately before or behind the cornea and examine the image closely, noting the effect upon the brightness and the sharpness of the image. Explain.

4D. Astigmatism
With the retina in the normal position, insert the cylindrical lens No. 5 at $\mathbf{G_1}$ immediately behind the cornea with its axis vertical. With the object at the normal viewing distance, observe the character of the image. Place the cylindrical spectacle lens No. 6 in front of the cornea and rotate it in the support until the image is most sharply defined. Note the direction of the axis of the spectacle lens. Repeat with the rear lens at a different angle.

4E. Compound Defects
Using the cylindrical lens No. 5 at $\mathbf{G_1}$, combine astigmatism with myopia or hypermetropia by making suitable adjustment of the retina. Make the correction by using the proper combination of spectacle lenses. Describe the shape of a single lens that would make the same correction.

4F. Removal of the Crystalline Lens
The crystalline lens is only one part of the lens system of the eye. Sometimes (for instance, in the case of cataract) it has to be removed. Take out the crystalline lens and show, by using Lens No. 1 as a spectacle lens in front of the eye, that vision is still possible. Note that the image is distinct only for very near objects.

4G. The Use of a Magnifier, or Reading Glass
With the retina in the normal position, insert lens No. 2 as the crystalline lens. Determine approximately the diameter of the image with the object box at the normal distance. Use lens No. 1 as a magnifier in front of the eye and adjust the viewing distance until the image is distinct. Compare the ratio of the image sizes with the ratio of the viewing distances.

5. Questions

1. Approximately how much brighter is the image without the diaphragm than with it? Explain.

2. Apply the test described in the sub-section on "Spectacle Lenses" (see page 5) to lens Nos. 3, 4, and 6 and describe the results.

3. From the marked values of the dioptry, calculate the focal lengths of lens Nos. 1 and 2 and compare with the values obtained experimentally by forming the image of a distant object.

4. Is the focal length of a lens greater in water or in air? Explain.

5. Would a given lens have the same effective focal length when used at **C** as at **L** (see Figure 6)? Explain.

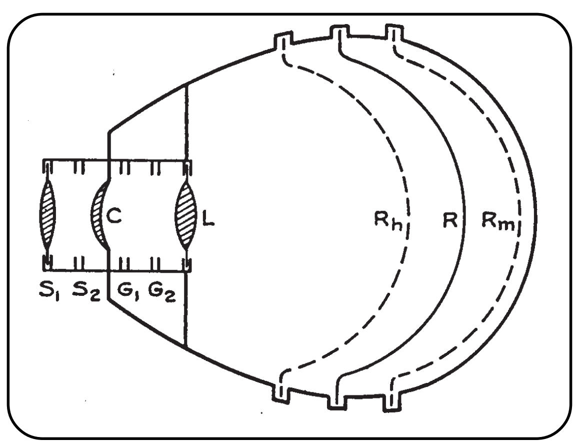

Figure 6 Plan of Eye Model.

6. What harm, if any, would be done by rotating the spectacle lenses of a near-sighted person in their frames? What if the individual had astigmatic correction?

6. Maintenance

The Ingersoll Eye Model needs no special maintenance. Be sure to empty and dry the tank after use, and protect the lenses from scratching or breakage. If you need to replace the lamp in the optical object box, use a 40-watt, 120-volt incandescent bulb.

If any difficulty develops with this apparatus, contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any item to Central Scientific Company until we have sent you authorization.

7. Replacement Parts and Accessories

Description	Cat. No.
Optical Lens Set (six)	87666-01
Advanced Lathe-Bed Optical Bench	85801
Hinged Optical Bench Carriage	85802
Threaded 1 x 15cm Aluminum Rod with Shoulder	72165-01

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