The Human Eye

Materials

1. Colored pencils
2. Crosshaired light source
3. Flashlight
4. Optical bench
5. Plastic eye model (with lenses, aperture, etc.)

Introduction

The eye model (represented by Figure 1) consists of a metal tank shaped roughly like a horizontal cross section of an eye. Water in the tank will play the roles of the aqueous and vitreous humors. The role of the retina is played by a curved metal sheet (R in Figure 1) with a circular white region on it. The dotted circle on the retina is the border of the fovea, the small central region that is sensitive to details. A two-element lens accomplishes image formation in an eye. The first element, the cornea, is represented by the curved lens that forms the window in the tank (C). The role of the second element (the "crystalline" lens inside the eye) will be played by a glass lens placed in the groove (L) at the septum, the dividing wall near the front of the tank. In a real eye the crystalline lens has a shape, and power, that can be adjusted by muscles. This allows us to focus on objects at different distances from us. In the model eye, we will simulate this accommodation by using different focal length glass lenses at this septum position.

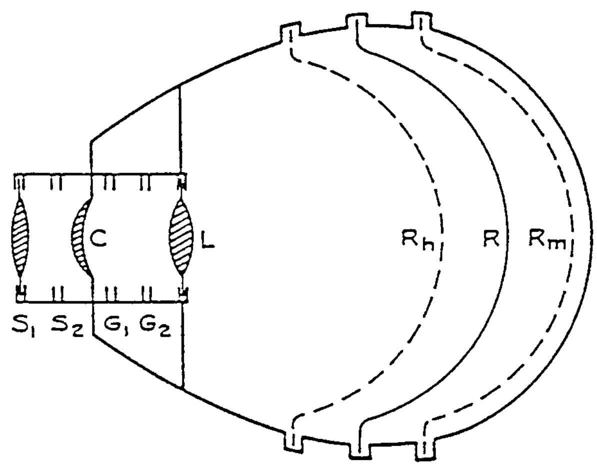

Figure 1: *The Model Eye (Courtesy of CENCO)*

Listed in Table 1 are the lenses available for use with the model. The last two, the cylindrical lenses, are used only in connection with astigmatism. Power in diopters is 1/(focal length in meters). In addition to the lenses there is a small circular opening to simulate a contracted pupil.

Lens No.	**Lens Type**	**Focal Length** (mm)	**Power in Diopters** (diopters)
1	spherical convex	+120	+8.33
2	spherical convex	+62	+16.00
3	spherical convex	+400	+2.50
4	spherical concave	−1000	−1.00
5	cylindrical concave	−128	−7.81
6	cylindrical convex	+307	+3.25

Table 1: *Lens type, focal length, and power (in diopters) of the lenses available for use with the model eye.*

Procedure

In each of the following experiments observe and record how the size and orientation of the image on the retina of the model eye compared to the properties of the object being imaged.

Part 1: Accommodation

Look with your own eye toward some distant object; then change and look at some writing very close to you. To allow you to see both distant and nearby objects clearly the crystalline lens of your eye is changing shape and therefore power. Let's model this behavior. With the tank filled with water to within one to two centimeters of the top and with the retina in its normal (middle) position (R), place lens #1 at the septum (L) to act as the crystalline lens. Face the eye toward some distant outdoor object (or an indoor substitute if necessary). You should see a clear image on the retina. Now, to simulate the viewing of a nearer object, place the lighted object box about 35 cm in front of the eye. [Q1] Is the image on the retina clear? Simulate the changing shape of the crystalline lens by replacing lens #1 by lens #2. [Q2] Is the image now clearer? [Q3] Is the image larger or smaller than the object? [Q4] What about the orientation of the image? [Q5] From what you have just observed, what do you think happened to the shape of your own eye's crystalline lens when you went from viewing a distant object to viewing one closer to you?

Part 2: Farsightedness and Nearsightedness

In these investigations the starting position is with the object box 35cm from the eye and with lens #2 as the crystalline lens. In farsightedness (hypermetropia), when imaging a nearby object, the eye's lens does not converge light fast enough to form a clear image. The image is formed behind the retina, or, rather, it would form in the space behind the retina's normal position if the retina were absent. To simulate this effect shorten the model eyeball by moving the retina to its forward position (R_h). Slide the retina straight up and then straight back down into the other slots. Note the unclear image. Now let's correct this defect by fitting the appropriate corrective lens in a slot in front of the cornea (S_1 or S_2). Try lenses 1, 3, and 4. [Q6] Which type of lens corrects for farsightedness? Now, without removing the corrective lens, return the retina to its normal (middle) position. This should illustrate what happens when a person with good vision wears the glasses of a farsighted person. After removing the corrective lens, perform a similar investigation of nearsightedness (myopia) in which the eye's lens converges the light too quickly, thereby forming an image in front of the retina. Simulate this condition in the model eye by moving the retina to its back position (R_m). Select a corrective lens that makes the image clear. [Q7] What type of lens corrects for nearsightedness? Actually, most nearsighted eyes might see an object 35 cm away quite clearly. The problem would arise with more distant objects. We've simulated the problem for a closer object because of the inconvenience of using this model with distant objects.

Part 3: Pupil Size

Start with a normal eye (middle retina position and #2 as crystalline lens and with the object box at 35cm). Note the brightness and clarity of the image. Simulate a contraction of the pupil by placing the small circular opening just behind the cornea (G_1). [Q8] What happens to the image? Now, remove the small pupil again. Move the object box a little closer or farther away until the image becomes somewhat fuzzy. Place the small pupil back in position. [Q9] What is the effect on the sharpness of the image? [Q10] Do you see why a person who needs glasses but is not wearing them can sometimes see more clearly by squinting or looking through a small hole?

Part 4: Use of a Magnifier

Go back to the "normal" eye setup. Measure and record the size of the image on the retina. Then use lens #1 as a magnifier by placing it in one of the slots in front of the cornea. Adjust the distance to the object box until there is a clear image. Again measure and record the size of the image on the retina. [Q11] What magnification was achieved? (Show your calculations.) Try viewing a small detail on your finger with your naked eye and then with your eye aided by the magnifier held next to your eye. [Q12] What magnification are you getting?

Part 5: Astigmatism

In astigmatism the eye's lens is, in effect, somewhat cylindrical in shape, which causes it to have a different focus in one plane through it than in a perpendicular plane. To simulate this effect begin with the normal eye setup and then place lens #5 just behind the cornea (G_1). Note the effect on the image. To correct this defect, place lens #6 in front of the cornea. Note that you will have to rotate this corrective lens about its axis to the appropriate position to

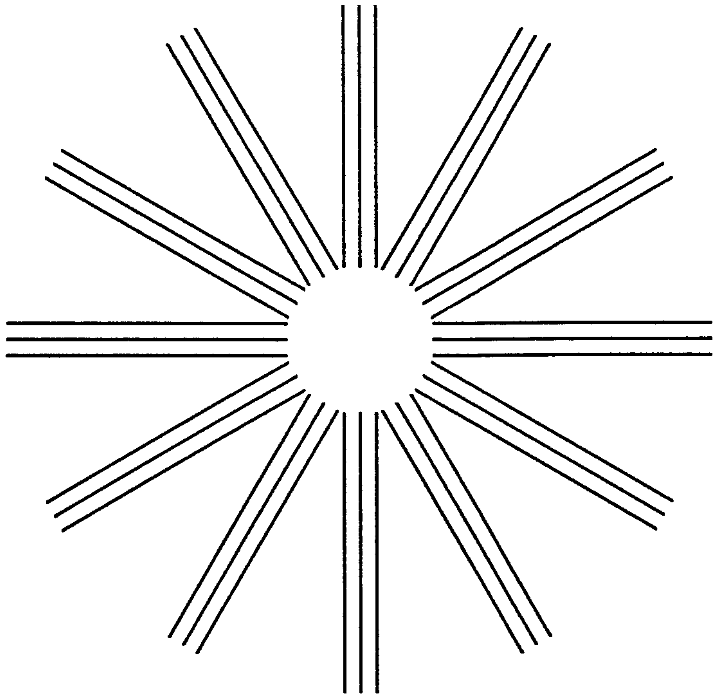

Figure 2: *Astigmatism Test*

get a clear image. Change the orientation of the defect by rotating lens #5. [Q13] What is now required of the corrective lens? An optometrist or ophthalmologist rotates his sample corrective lens while getting feedback from the patient to find the position of a cylindrical lens that will correct for astigmatism in that person's eye. The prescription will have to specify this orientation.

You can test for astigmatism in your own eye by viewing the diagram in Figure 2. If you have no astigmatism all spokes will be equally clear. If horizontal (or some other orientation) spokes are in sharper focus than those at right angles, you have some astigmatism. If you have little or none, you can simulate the defect by viewing the diagram through lens #6. Watch the pattern change as you rotate the lens.

Create and correct compound defects such as astigmatism plus nearsightedness. [Q14] What combination of corrective lenses is required? Luckily these corrective properties can be ground onto a single lens.

Part 6: Absence of the Crystalline Lens

In some people, particularly those with serious cataracts, the crystalline lens is removed surgically. (Nowadays, in such cases, it is usually replaced by a plastic implant lens. But in times past it was not replaced. Surgically removed lenses are generally not replaced for children born with cataracts until about age twenty, as the implanted lens cannot grow with the eye and would become useless after a few months in a developing eye.) Remove the crystalline lens from the eye model. [Q15] Is there a clear image? [Q16] Can you come up with a corrective lens or combination of lenses in front of the eye that will give a clear image for any possible object position? You should find more than one possibility. [D1] Explain why people who had cataract surgery long ago used to have to wear very thick glasses?

Cleanup: Please remove all lenses from the model. Gently dry off the lenses and place them in their case. Pour the water from the tank into the sink. Be sure to turn off the object box light.

Additional Experiments with Your Eye

Color Vision

While you stare straight ahead at some fixed object, have your partner bring a colored object (whose color is unknown to you) slowly from behind you, keeping the object about two feet from your head. As it swings around toward the front be careful to keep your eyes straight ahead. Signal when you first see the object and again when you can identify its color. Estimate the fraction of your retina that is sensitive to color. [Q17] What is the angle at which point you first saw the color correctly. Measure the angle from straight ahead—i.e., let straight ahead be $0°$.

Sharp Vision

Have your lab partner put a large X in the center of one of the small squares near the center of a piece of graph paper. Cover one of your eyes and stare at the X with the paper about $1^1/_2$ feet away. Concentrate on staring at the X; do not let your eye move no matter how tempted you are. It is okay to blink. As your partner puts small letters or numbers in surrounding squares, name them. Remember, keep your eye on the X. [Q18] How far away from the X are the letters clear to you? [Q19] What is the angle created at the eye with the farthest clear letter?

Blind Spot

Note the large black dot on the retina of the model eye. It represents the blind spot on the retina where the optic nerve leaves for the brain. The following exercise should reveal your own blind spot (you do have one, even if you think you don't). Start again with an X in the center of a sheet of paper. Close your left eye, and stare steadily at the X with your right eye with the paper about a foot from you. Continue to stare only at the X as your partner places a pen point on the X and slowly moves the pen to your right. [Q20] Is there a place where the point disappears? [Q21] Does it reappear as the motion continues? Repeat for motion to the left. Do a similar experiment with your left eye. [Q22] What do you conclude?

[Q23] Is the optic nerve on the nose or temple side of the retina? (Remember the tendency of converging lenses to form inverted images.) As an alternative, search for the blind spot in your right eye, with your left eye closed, stare at the X below as you slowly move the page closer or farther away. At some distance the O should disappear because its image is on the blind spot. Devise a similar test for the left eye.

X **O**

Far Point and Near Point

If you wear corrective lenses try to perform these measurements with and without them. You should be able to focus on an object very far away. If so, your far point is at infinity. If not, measure the greatest distance at which you can focus. [Q24] For a person who cannot focus on very distant objects, where is the eye forming the image, in front of or behind the retina? Now measure the smallest distance at which you can focus clearly. Usually, this distance increases with age. [Q25] If your near point is very large, what vision defect do you have? [Q26] Why do some people need bifocal or even trifocal glasses?