

The Human Eye Lab 3

Equipment PASCO human eye model with accessories (eye model placed on end of bench away from wall), goose neck lamp, 2 meter ruler, 3x5 in card with “P” about 1.6 in high (for close objects), $8\frac{1}{2} \times 8\frac{1}{2}$ in card with “P” about $6\frac{1}{4}$ in high (for distant objects), 3x5 in card with thick astigmatism lines, $2\frac{1}{2} \times 5$ in card for observing focus of distant object, clean water to fill lens model, toweling to lay wet lenses down on, 6 ft. lab bench preferred, copy of blind spot Fig. 4 as 1 in strip

Reading Your textbook

Optional Reading “Stargazer: the life and times of the TELESCOPE,” Fred Watson (Da Capo 2004).

PRECAUTION

THE LENSES USED IN THIS EXPERIMENT ARE PLASTIC AND FAIRLY SOFT. SOME OF THESE LENSES WILL BE USED IN WATER. PLEASE DO NOT RUB OR WIPE THEM DRY, AS THIS WILL ULTIMATELY SCRATCH THEM. JUST LAY THEM DOWN ON SOFT TOWELING.

1 Introduction

In this experiment you will examine images formed by a PASCO model of the human eye. Eye defects, such as near-sightedness(myopia), far sightedness (hyperopia), and astigmatism can be introduced into the model, and corrected with exterior lenses which represent eye glasses as worn by many of us. Included is a bit of history about lenses and telescopes.

2 Brief History of Lenses and Telescopes

Lenses have been around awhile. The British Museum has a rock crystal lens called the Nimrud lens which has been reliably dated to the seventh century BC. (Nimrud is the Assyrian capital in which the lens was found.) Earlier lenses have been found. These lenses were short focal length lenses suitable for use as magnifying glasses. Spectacles using convex lenses, which are a help with far sightedness, probably first appeared in Italy late in the thirteenth century. Spectacles with concave lenses, a help with near sightedness, appeared in Italy in the middle of the fifteenth century. (Concave lenses are harder to make than convex lenses.) In spite of much conjecture, the telescope was probably not invented until early in the seventeenth century. A number of opticians at around the same time produced versions of this useful instrument. The refracting telescope (using lenses and not mirrors) requires a long focal length objective lens of some precision. The means of producing such a lens were not available earlier. Galileo was not the first to turn a telescope toward the heavens, but his observation that Jupiter had moons, which implied not everything revolved around the Earth, and that Venus had phases, which implied Venus revolved around the Sun and not the Earth, did not win him Brownie Points with the authorities.

3 Preliminary Remarks

- The word “object” in this write-up refers to the entity that is imaged by the model eye. The objects used are two sizes of the letter “P”.
- Let f be the focal length of a lens, n be the index of refraction of the lens material, and n_m the index of refraction of the medium in which the lens is immersed. Then it can be shown that $1/f$ is proportional to $(n - n_m)$. The greater the difference in the indexes of refraction the stronger the lens (the shorter the focal length). Except for the outer surface of the cornea the lens surfaces of the human are in material whose index of refraction is close to that of water. As a result these lenses are weaker than they would be in air.
- The focal lengths f marked on the lenses are for the lenses in air. The index of refraction of air is about $1.0003 \cong 1.000$. The focal length f_ℓ of one of these lenses in a liquid of index of refraction n_ℓ is given by

$$f_\ell = \left[\frac{n_\ell(n - 1)}{n - n_\ell} \right] f, \quad (1)$$

where n is the index of refraction of the lens material. For example, the polycarbonate lens ($n = 1.586$) marked as having a focal length of 62mm will have a focal length of 191 mm in water ($n_\ell = 1.333$).

- Most of the refraction in the eye takes place at the outer surface of the cornea.
- The crystalline lens of the human eye has an index of refraction of about 1.437.
- Place the model of the eye at the end of the bench furthest from the wall. To change the eye-object distance, move the object.
- Farsightedness is called both hypermetropia and hyperopia.
- The longer the focal length of a lens, the weaker the lens. If the focal length is given in meters, the inverse of the focal length is the strength of the lens in *diopters*.
- There are two kinds of light sensitive cells in the eye, rods and cones. They get their names from their shapes. Rods are more light sensitive than cones, deliver lower resolutions than cones, and give black and white images. Cones give higher resolution and color vision, but are less light sensitive than rods.

4 The Human Eye

Please see Fig. 1. The eye is roughly a sphere with a diameter of about 24 mm. Light is admitted to the eye by the cornea (the corneal lens), passes through the pupil which is a hole in a variable diaphragm called the iris, travels through the crystalline lens, and impinges on the retina. A real inverted image is formed on the retina. Most of the focusing is done by the outer surface of the cornea. Further focusing is done by the crystalline lens. The shape and focal length of the crystalline lens can be changed by the ciliary muscles. Between the cornea and crystalline lens is a clear fluid called the aqueous humor. Between the crystalline lens and the retina is a clear gel called the vitreous humor. Both humors have an index of

refraction close to that of water. The retina, which covers about 65% of the back of the eyeball, is covered by light sensitive cells. These cells convert light energy to nerve impulses. Where the optic nerve passes through the retina there are no light sensitive cells. This results in a “blind spot.” The fovea is a small area in the center of the retina that has only cone cells and is responsible for the most acute vision.

Light reflected from an object enters the eye and a real inverted image is formed on the retina. For an eye with no pathologies an object at infinity will be in focus at the retina with the ciliary muscles fully relaxed (crystalline lens weakest). Infinity is called the “far point.” As the object is moved toward the eye, the ciliary muscles contract and the crystalline lens become more curved decreasing the focal length. The smallest object distance that results in a sharp focus is termed the “near point.” A young person has a near point of about 7 cm. The ability of the eye to focus at different distances is called accommodation. The near point recedes with age, a condition termed presbyopia.

5 The PASCO Human Eye Model

Fig. 2 shows a cross section of the plastic eye model. It is a container open at the top so that it can be filled with water. The water takes the place of the aqueous and vitreous humors. A plano-convex lens rigidly attached to the model serves as the corneal lens. Outside slots marked 1 and 2 are for the insertion of corrective lenses (eye glasses). A slot inside the model marked *septum* is for the insertion of a lens that serves as the crystalline lens. Adjacent to the septum slot are slots labeled A and B. These two slots are for the insertion of lenses that change the focal length of our model crystalline lens and can also introduce astigmatism. (Note: In the human eye the crystalline lenses change focal length by being distorted by the ciliary muscles. In the model, the focal length of the crystalline lens is changed by changing the lens or adding extra lenses.)

Diametrically across from the slots just mentioned are 3 slots labeled normal, near, and far. These slots are for a screen that serves as the retina. It is on this screen that you observe images of an object. These slots allow the distance between the model crystalline lens and the model retina to be changed. To mimic the normal, farsighted, and near sighted eye the screen is respectively moved to the slots marked normal, far, and near. The screen has a hole in it to simulate the blind spot of the retina.

5.1 The Eye Model Lenses

These are plastic and should be treated with care. They scratch easily. The lenses are held by plastic holders that have handles for easy handling and insertion into the various slots in the eye model. The lens holders allow for about 90 deg rotation when a lens is in a slot of the eye model. On each lens holder is printed the focal length of the lens *in air* with a plus sign for a converging lens and a minus sign for a diverging lens. When a particular lens is called for these number will be referred to. For example, a converging lens with a focal length of 120 mm in air will be referred to a +120 mm lens.

5.2 Lens Data

A table of specifications at the end of this write-up gives data on the lenses supplied with the model. There are three spherical convergent lenses, one spherical divergent lens, one

convergent cylindrical lens, and one divergent cylindrical lens. Each cylindrical lens has two notches in its frame that denote the axis of the lens. All the lenses have handles for easy insertion into the slots and for easy removal from the slots. Note that the index of refraction depends slightly on wavelength.

5.3 Objects and Light source

Two objects supplied are a large “P” and a small “P” written on cards. The image gets small as the object distance increases, so use the small P for small object distances and the larger P for large object distances. Illuminate a card with a goose-neck lamp placed fairly close to the card and off to the side a bit. The “center” of the eye model’s two lens system is approximately the top rim of the model. Measure object distances from this point unless otherwise advised. To measure image sizes, use the calipers provided. Keep the eye model at the end of the lab bench away from the wall and change the object distance by moving the card. Use the meter stick to measure object distances.

To detect astigmatism, use the card with a “star” on it.

NOTE In what follows, the focal lengths and distances refer to the eye model, not the human eye. Because the eye model is scaled up, the focal lengths and distances are correspondingly larger.

6 The Corneal Lens in Air

The focal length and image properties of the model’s corneal lens in air are investigated. The eye model should be empty (no water) and there should be no lenses present except the corneal lens. (The corneal lens of the eye model cannot be removed.) With the eye model at one end of the bench and the large P at the other end of the bench use the $2\frac{1}{2} \times 5$ in card in the region of the retina screen slots to form a clear image on the card. Measure the object and image distances from the corneal lens, not the top rim of the eye model (there is no crystalline lens present). Use the thin lens formula to calculate the focal length of the corneal lens in air and compare to that given by the lens specification sheet. Do not fill the eye model with water, but if you did, do you think an image could be formed by the corneal lens within the body of the eye model? Why or why not?

Examine the image of the object P. Explain how the image P differs from the object P. In particular, have up and down been interchanged? How about left and right? What happens to left and right when you turn your head to look from the object to the image or vice versa? Would an object “I” or an object “D” provide as much information as the object P?

Measure the image size using the calipers and a ruler and measure the object size using a ruler. From these quantities calculate the magnification, providing the correct sign. Also calculate the magnification from the object and image distances and compare with your measured value.

7 The Normal Eye

When the ciliary muscles are relaxed the crystalline lens of the human eye is weakest and has the longest focal length. Under these circumstances a human eye with good vision focuses a

distant object (technically at infinity) on the retina. For the eye model this corresponds to a crystalline lens with a focal length of about +120 mm. The eye model should be empty. Put the retinal screen in the normal position and insert the converging lens with a focal length of 120 mm in air in the septum. Using the small object P determine the object distance that produces a focus. Move the object up and down and horizontally. How does the image move when you make these motions?

Fill the eye model with water to within about 1 or 2 cm of the rim. With the eye model at one end of the bench and the large object P at the other end of the bench is there a reasonable focus on the retinal screen? Actually, the object is far away from the eye model but not at infinity. Do you get a slightly better focus if you put the screen in the near slot or the far slot?

Suppose a person with normal vision wants to focus on a nearby object. That person will tighten the ciliary muscles squeeze the crystalline lens and make it more curved. The crystalline lens becomes stronger with a shorter focal length and enables the person to focus nearby objects. We can't squeeze the model lenses but we can replace them with stronger lens to mimic the effect. Remove the +120 cm lens and replace it with the stronger +62 mm lens. At what distance does the model eye now focus?

The ability of the human eye to focus at different object distances is called accommodation. The nearest distance that can be focused is called the near point. This is about 7 cm for a rather young person, but recedes with age. At age 60 y it might be 200 cm. This decrease of accommodation with age is called presbyopia.

8 Normal Near Vision

You will be asked several times to set the model eye for “normal near vision.” This means that

1. the eye model is filled with water,
2. the +62 mm lens is in the septum slot, and
3. the screen is in the normal position.

9 Myopia (Near Sightedness)

An eye with myopia focuses an image in front of the retina. This can be interpreted in one of two ways:

1. the crystalline lens is too strong, or
2. crystalline lens-retina distance too long.

For producing myopia in the eye model the second interpretation will be used. Set the model up for normal near vision. Get the small object P in focus on the screen. Now move the screen to the near slot (further away from the crystalline lens) and describe the image. See if among the spherical lenses provided you can find a lens that when inserted in slot 2 makes the image sharp. This lens is an “eye glass.” Describe how it works.

10 Hyperopia or Hypermetropia (Far sightedness)

An eye with hyperopia focuses an image in back of the retina. This can be interpreted in one of two ways:

1. the crystalline lens is too weak, or
2. the crystalline lens-retina distance is too short.

For producing hyperopia in the eye model the second interpretation will be used. Set the model up for normal near vision. Get the small object P in focus on the screen. Now move the screen to the far slot (closer to the crystalline lens) and describe the image. See if among the spherical lenses provided you can find a lens that when inserted in slot 2 makes the image sharp. Describe how this “eye glass” works.

11 Astigmatism

A normal eye has spherical lenses. If one of the lenses is not purely spherical but is partly cylindrical the eye is said to have astigmatism. The result is a blurred image.

Fig. 3 is an astigmatism chart. If you wear glasses remove them. Cover one eye and look at the chart. If you have astigmatism some of the lines will appear darker than others. If you removed glasses, put them on and look at the chart again. Is there any improvement?

In the eye model lenses astigmatism is not incorporated into the spherical lenses the way it is in the human eye. In the model astigmatism is produced by a lens that is purely cylindrical and has no spherical component. The corrective lens that will be used is also purely cylindrical. Look at the spherical and cylindrical lenses provided edge on and observe the difference.

Set up the eye model for normal near vision. Adjust the position of the small object P so that the image is in focus on the screen. Leave the object P in this position. Insert the -128 mm cylindrical lens in slot A with the side of the lens handle marked with the focal length facing the light source. Describe the image. Rotate the lens with the handle as much as possible. Does the appearance of the image change? (The axis of both cylindrical lenses provided is along a line that goes through the notches on the lens holders.)

Correct for the astigmatism by inserting the $+307\text{ mm}$ cylindrical lens in slot 1 with the side of the lens handle marked with the focal length facing the light source. Rotate the handles of the two cylindrical with respect to each other. When do you get the best focus? Leave the lenses and object where they are.

11.1 Hyperopia Plus Astigmatism

A human eye often has myopia or hyperopia and astigmatism at the same time. Model an eye that has both hyperopia and astigmatism. Find two lenses that when inserted into slots 1 and 2 correct for these conditions. Note that you have corrected this dual condition by using two lenses, while an optometrist would correct the two conditions with one lens that has both spherical and cylindrical curvature.

12 Blind Spot

The nerves that carry the electrical signals from the light sensitive cells (rods and cones) on the surface of the retina all go through the retina at the same spot. There are no light sensitive cells at this point. This spot is called the blind spot and in the eye model is depicted by a hole in the retina screen. After passing through the retina the nerves go to the brain where the sensation of seeing is formed.

Experience the blind spot as follows. Fig. 4 has a plus sign on the left and a black dot on the right. Cover your left eye, look at the plus sign with your right eye, and look at the plus sign, holding Fig. 4 about 40 cm from your right eye. Bring the Fig. 4 closer to you. At some point you should see the black dot disappear. The image of the dot has been focused onto your blind spot. If you bring the Fig. 4 still closer, the dot should reappear. Why?

Try the same experiment with left eye, covering your right eye. To make the experiment work, what must you do with the Fig. 4?

Fig. 5 is similar to Fig. 4 except that the black dot is at the center of a large plus sign. Try the same experiments. When the blind spot is reached what do you see? The brain fills in for the missing material, using the image next to the blind spot for extrapolation!

Set the eye model up for normal near vision. Use the strip copy of Fig. 4 as an object and see if you can get an image with the plus sign at the center of the screen and the dot at the position of the hole in the screen. Is the eye model for a left or right eye?

13 The Pupil

In the human eye the pupil is a variable diaphragm. The pupil opens up in dim light to allow more light to fall on the retina and closes down in bright light to prevent too much light from falling on the retina. The eye functions for an enormous range of light intensities.

The size of the pupil also determines the “depth of field” of the eye. The depth of field is the range of object distances for which the image is “in focus.” Spherical lenses have aberrations that increase as the diaphragm associated with a lens increases in diameter. With an increase of diaphragm diameter the depth of field decreases.

Set the eye model up for normal near vision and focus the small object P on the screen. Insert the circular model pupil in slot B. Does the intensity of the image change? Does the sharpness of the image change. Remove the model pupil and move the screen to the far slot. How does the image appear. What happens to the image when the model pupil is inserted in slot B? Try the same procedures when the screen is moved to the near slot.

For camera buffs, the f-number is defined as f/D , where f is the focal length of the lens and D is the diameter of the diaphragm. A smaller f-number results in less depth of field and more light on the photosensitive media. Standard f-numbers are 2, 2.8, 4, 5.6, 8, 11, and 16. By about what factor does the amount of light striking the photosensitive media change when you switch to the next lowest f-number, assuming the focal length of the lens does not change? Photographers will sometimes choose a smaller f-number than necessary so as to make the background fuzzy (out of focus).

14 Finishing Up

Please leave the bench as you found it. Thank you.