## Experiment

**12**

Optics of the Human Eye

# Introduction

In this experiment you will study how images are formed on the retina of the eye. Before you start, draw a diagram of the eye model and identify the parts of the human eye represented by each part of the model. Please read the supplementary handout and review the concepts of image formation via refraction (thin lens equation):

Your report will only consist of the Data, Analysis, and Results section, don’t print the procedure. NOTE: You will need a minimum of two hours to collect the data!!!

**Part 1: Images Formed in the Eye**

**Procedure**

1. Do not fill the eye model with water yet. Put the retina screen in the middle slot, marked NORMAL. Put the +400 mm lens in the slot labeled SEPTUM.
2. Put your hand in front of the eye model, about 50 cm from the cornea. Use your desk lamp to brightly illuminate your hand. Move your hand up, down, left, and right. Note your observations. You will be asked a question about this in the “Data, Results, & Analysis” section.



**Part 2: Accommodation**

The focus of this part of experiment is to learn about the process of accommodation. This is a process in which the muscles in the eye change the shape of the crystal-line lens to change its focal length. Changing the lens or lenses that represent the crystalline lens simulates accommodation in the eye model. In addition to accommodation you will also learn:

1. how a change in the medium affects the focal length of a lens.
2. how to determine the near point of the eye (also called distance of distinct vision).
3. how the pupil and the iris affects vision.
4. about far vision (the fully relaxed eye).

**Procedure**

1. Do not fill the eye model with water yet, and leave the +400 mm lens in the SEPTUM slot. Position the eye model about 50 cm from the light source (notice that the position of the light source is several cm from the zero mark on the tape of the optics bench), with the eye looking directly at the illuminated screen. Can you see clear image on the retina? Record your observation in Table 2.1. Repeat the procedure with the +62mm lens in the SEPTUM slot.
2. Replace the +62mm lens with the +400mm lens. Fill the eye model with water to within 1 or 2 cm from the top. Return it to the same position as in step 1. Is the image in focus? Record your observation in Table 2.1 and answer question 1 of Part 2 in the “Data, Analysis, and Results” section. Repeat the procedure with the +62mm lens in the SEPTUM slot.



1. Place the eye model about 50 cm from the light source. Place the +62 mm lens in the SEPTUM slot. Move the eye model as close as possible to the light source while keeping the image in focus.
2. At the closest position, measure the object distance, ***o***, from the screen of the light source to the top rim of the eye model, as pictured below. (The front of the rim is a convenient place to measure to and marks the center of the eye model’s two-lens system.) Record this distance in Table 2.2. This distance is the **near point** of the eye model when equipped with the +62 mm lens. The average human eye has a near point for distinct vision of about 25 cm.

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1. The optics of a two-lens system can be simplified looking at the combined effect of the lenses and the total *effective* focal length of the system. Measure and record (Table 2.2) the image distance (*i*), from the model’s rim to the handle of the retina.
2. Increase the ability of the eye model to focus on a close object by adding the +400 mm lens to slot B. This combination models a different focal length for the crystalline lens. Adjust the object distance until a clear image is seen on the retina. Record the image and object distance in Table 2.2. Then calculate the effective focal length of the system.
3. Keep the +400 mm lens in slot B and replace the lens in the SEPTUM slot with the +120 mm lens. At what nearest distance does the model eye focus now? Record the image and object distance in Table 2.2. Then calculate the effective focal length of the system.
4. Remove both lenses and place the +62 mm lens in the SEPTUM slot. Adjust the eye-source distance so that it is about 5cm less than “near point” distance for this lens (which you found in step 4). The image should be slightly out of focus. While looking at the image, place the round pupil in slot A. What changes occur in the brightness and clarity of the image? Try it and answer question #6 of the Part 2 in the “Data, Analysis, and Results” section.
5. Position the eye model (with pupil removed) so that it is looking towards a *distant* object (about 3m away). Is the image on the retina in focus? Replace the lens in the SEPTUM slot with one that makes a clear image of the distant object; this is the **far-vision lens**. Record the focal length marked on the handle of the lens in Table 2.2.

**Part 3: Hypermetropia**

A person affected by hypermetropia has a shorter-than-normal eyeball, making the retina too close to the lens system. This causes images of near objects to be formed behind the retina.

**Procedure**

1. Set the eye model (still filled with water) to normal near vision (put the 62 mm lens in the SEPTUM slot, remove other lenses, and make sure the retina is in the NORMAL position). Position the eye to look at the nearby light source. Adjust the eye-source distance to the near-point distance so that the image is in focus. Measure and record the image distance and the object distance Part 3 of the “Data, Analysis, and Results” section.
2. Move the retina screen to the forward slot, labeled FAR. Describe what happens to the image. This is what a far-sighted person sees when trying to look at a near object. Measure and record the retina distance (distance from the model’s rim to the handle of the retina) in Part 3 of the “Data, Analysis, and Results” section. The object distance will be the same as in the previous step. Decrease the pupil size by placing the round pupil in slot A. Note what happens to the clarity of the image (see Part 3 Item 2 in the “Data, Analysis, and Results” section). Remove the pupil.
3. Turn the eye model to look at the distant object (3 meters or greater), and describe the image. Does a far-sighted person have trouble seeing distant objects? **Circle: Yes or No**
4. Return the eye model to looking at the nearby light source. You will now correct the hypermetropia by putting eyeglasses on the model. Find a lens that brings the image into focus when you place it in front of the eye in slot 1. Measure and record the retina distance and the object distance in Table 3.1. Record the focal length of the corrective lens in Part 3 of the “Data, Analysis, and Results” section. **Does rotating the eyeglasses lens in the slot affect the image? Circle: Yes or No**
5. A corrective lens is not usually described by its focal length, but rather by its light-bending **power**, which is measured in units called **diopters**. To calculate a lens’s power in diopters, take the reciprocal of its focal length *in meters*. You will be asked to calculate the power of the eyeglasses lens that you selected for the model eye in Part 3 Item 3 in the “Data, Analysis, and Results” section.

**Part 4: Astigmatism**

In a normal eye, the lens surfaces are spherical and rotationally symmetrical; but an eye with astigmatism has lens surfaces that are not rotationally symmetrical. This makes the eye able to focus sharply only on lines of certain orientations, and all other lines look blurred. Astigmatism can be corrected with a cylindrical eyeglasses lens that is oriented to cancel out the defect in the eye. Each cylindrical lens included with the eye model has its cylindrical axis marked by two notches in the edge.

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In steps 1 through 6 of the following of the procedure, you will to need take notes of your observations in order to answer five questions in the Data, Results, and Analysis” section for Part 5.

**Procedure**

1. The figure below is a test chart for astigmatism. All of the lines are printed the same thickness and brightness, but a person with astigmatism sees some lines as darker than others.

Cover one eye and look at the chart. Do some of the lines look darker than others? If they do, rotate the figure 90° to convince yourself that the lines are actually the same and it is only your eye that causes the effect. If you wear glasses, look at the figure both with and without your glasses. Try rotating your glasses in front of your face while looking at the chart through one of the lenses.

1. Set the eye model (still filled with water) 25-30cm from the source (put the +62 mm lens in the SEPTUM slot remove other lenses, and put the retina screen in the NORMAL position).
2. Place the -128 mm cylindrical lens in slot A. The side of the lens handle marked with the focal length should be towards the light source. Describe the image formed by the eye with astigmatism.
3. Rotate the cylindrical lens. What happens to the image? This shows that astigmatism can have different directions depending on how the defect in the eye’s lens system is oriented.
4. You will now correct the astigmatism with eyeglasses. Place the +307 mm cylindrical lens in slot 1. The side of the lens handle marked with the focal length should be towards the light source.

Rotate the corrective lens and describe what happens to the image. Find the orientation of the eyeglasses lens at which the image is sharpest. What is the angle between the cylindrical axes of the crystalline lens and the corrective lens?

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**Part 5 (Optional-7 extra credit points max.): Myopia**

A person affected by myopia has a longer-than-normal eyeball, making the retina too far away from the lens system. This causes the image of a far-away object to be formed in front of the retina.

**Procedure**

1. Set the eye model (still filled with water) 40-45cm from the source (put the +62 mm lens in the SEPTUM slot, remove other lenses, and put the retina screen in the NORMAL position). With the eye model looking at the nearby light source, adjust the eye-source distance so that the image is in focus. Measure and record the image distance and the object distance in Part 4 of the “Data, Analysis, and Results” section.
2. Move the retina to the back slot labeled NEAR. Note what happens to the image. Measure and record the retina distance (distance from the model’s rim to the handle of the retina) and the object distance in Part 4 of the “Data, Analysis, and Results” section.
3. You will now correct the myopia by putting eyeglasses on the model. Find a lens that brings the image into focus when you place it in front of the eye in slot 1. Record the focal length of this lens. Calculate its power in diopters. Measure and record the image distance and the object distance in Part 3 of the “Data, Analysis, and Results” section. **Does rotating the eyeglasses lens in the slot affect the image? Circle: Yes or No.**
4. Remove the eyeglasses. Adjust the eye-source distance so that the image is in focus. Is this distance different from the normal near-point distance you found in step 1? Why?

**Data, Analysis, & Results:**

*Answer questions in complete sentences!*

**Part 1: Images Formed in the Eye**

1. Referring to Step 2 how does the image move as you move your have from left to right? Is the image inverted or upright?

**Part 2: Accommodation**

**Table 2.1**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Is the Image Focused (yes/no) | Focal Length in Septum (cm) | Inverted/Upright or can’t tell |
| Model no water |  | +400 |  |
| Model no water |  | +62 |  |
| Model with Water |  | +400 |  |
| Model with Water |  | +62 |  |

1. According to the data in Table 2.1, what happens to the focal length of a lens when it is immersed in water? What effect do the aqueous and vitreous humors (modeled by the water) have on the focal length of the eye’s lens system?
2. Using the results of Table 2.2, calculate the effective focal length of the corneal lens/crystalline lens system. Record in Table 2.2. We will need this value for **Parts 3 and 5**.
3. For the near point measurement, draw a ray diagram to scale on a separate sheet of GRAPH paper. *Clearly indicate title of the drawing, the scale factor, the object, the effective lens, the image, the object distance, and the image distance*. The ray tracing will be more effective if it is drawn in several colors of ink or pencil.
4. What does a real human eye do to change its focal length of the crystalline lens? What happens to the focal length and the curvature of the crystalline lens as an object is brought closer to the eye?
5. As a person ages the crystalline lens of the eye loses it elasticity. This is condition is called presbyopia. Does this condition affect your near point of your far point?
6. What effect does the pupil in Step 8 have on the image? Why does this happen?

**Table 2.2**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Object Dist. (cm) | Image Dist. (cm) | Effective Focal Length (cm) |
| Near Point Measurement |  |  |  |
| +400mm and +62mm lenses |  |  |  |
| +400mm and +120mm lenses |  |  |  |
| Far Vision Lens f=\_\_\_\_\_\_\_\_ | ∞ |  |  |

1. The modern treatment for cataracts is to surgically remove the crystalline lens and replace it with an artificial lens for far vision. How does this affect one’s visual ability read a book?

**Part 3: Hypermetropia**

**Normal Eye Data:**

 Object Distance\_\_\_\_\_\_\_\_\_\_\_\_\_

 Image Distance/Retina Distance\_\_\_\_\_\_\_\_\_\_\_\_\_

Focal Length \_\_\_\_\_\_\_\_\_\_\_\_\_

**Far-Sighted-Uncorrected Data:**

Retina Distance in FAR Position \_\_\_\_\_\_\_\_\_\_\_\_\_

 Image Distance \_\_\_\_\_\_\_\_\_\_\_\_\_

**Far-Sighted Corrected Data:**

Corrective Lens to Crystalline Lens Distance \_\_\_\_\_\_\_\_\_\_\_

Corrective Lens Focal Length \_\_\_\_\_\_\_\_\_\_\_\_\_

1. Why is the image blurred when the retina is moved to the FAR position?
2. In Step 2 you reduced the pupil size to observe the object. Did this make the image clearer? Explain your observations.
3. Calculate the power of the corrective lens in Step 5. Does a strong lens (high power) have a long or short focal length? How is this quantity related to the curvature of the lens?
4. Does the correction for hypermetropia require a convergent of divergent lens? Does it add or subtract from the light bending power of the lens?
5. Using your data, draw a ray-tracing to scale on a separate sheet of GRAPH paper. *Clearly indicate* the *title of the drawing, the scale factor, the objects, the effective lens, the virtual and real images, the object distance, and the image distances*. The ray tracing will be more effective if it is drawn in several colors of ink or pencil. Use the effective focal lens of the corneal-lens/crystalline lens system from Table 2.2 for your drawing.

**Part 4: Astigmatism**

1. How do the focusing properties of a cylindrical lens differ from those of a spherical lens?
2. Why does rotating the corrective lens for astigmatism affect the image, but rotating a corrective lens for hypermetropia or myopia does not?
3. What test could you do to find out if a person’s eyeglasses had a correction for astigmatism?
4. Look carefully at the -128 mm lens edge on, along the axis marked by the two notches. What shape do you see? Why is this lens described as cylindrical?

**Part 5 (Optional-7 extra credit points max.): Myopia**

**Normal Eye Data (2pts):**

 Object Distance\_\_\_\_\_\_\_\_\_\_\_\_\_

 Image Distance/Retina Distance\_\_\_\_\_\_\_\_\_\_\_\_\_

Focal Length \_\_\_\_\_\_\_\_\_\_\_\_\_

**Near-Sighted-Uncorrected Data:**

Retina Distance in NEAR Position \_\_\_\_\_\_\_\_\_\_\_\_\_

 Image Distance \_\_\_\_\_\_\_\_\_\_\_\_\_

**Near-Sighted Corrected Data:**

Corrective Lens to Crystalline Lens Distance \_\_\_\_\_\_\_\_\_\_\_

Corrective Lens Focal Length \_\_\_\_\_\_\_\_\_\_\_\_\_

* 1. Does the correction for myopia require a convergent of divergent lens? Why?(1pt)
	2. Using your data, draw a ray-tracing to scale on a separate sheet of GRAPH paper. *Clearly indicate* the *title of the drawing, the scale factor, the objects, the effective lens, the virtual and real images, the object distance, and the image distances*. The ray tracing will be more effective if it is drawn in several colors of ink or pencil. Use the effective focal lens of the corneal-lens/crystalline lens system from Table 2.2 for your drawing (4pts).