The Optics of the Eye [1]

(Adapted from the PASCO Manual All Eye Model images from Pasco)

The basic structure of the human eye consists of cornea, natural crystalline lens, and retina. The interior of the eye is filled with a transparent gel like substance called *vitreous humor (*refractive index n of 1.337). A water like fluid called *aqueous humor* (n=1.336) is filled between the cornea (n=1.376) and the lens (n=1.386-1.406) [1].

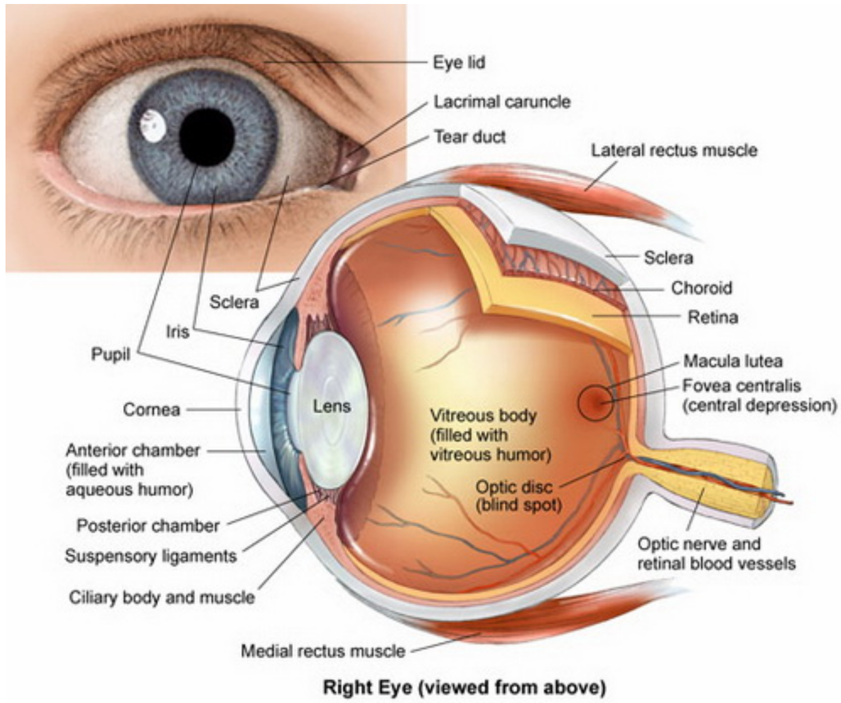


Figure 1: Diagram of the human eye

In this lab, you will experimentally test a scaled up model of the human eye to understand the image formed in the eye, the optics of accommodation, nearsightedness, and farsightedness [1-3].

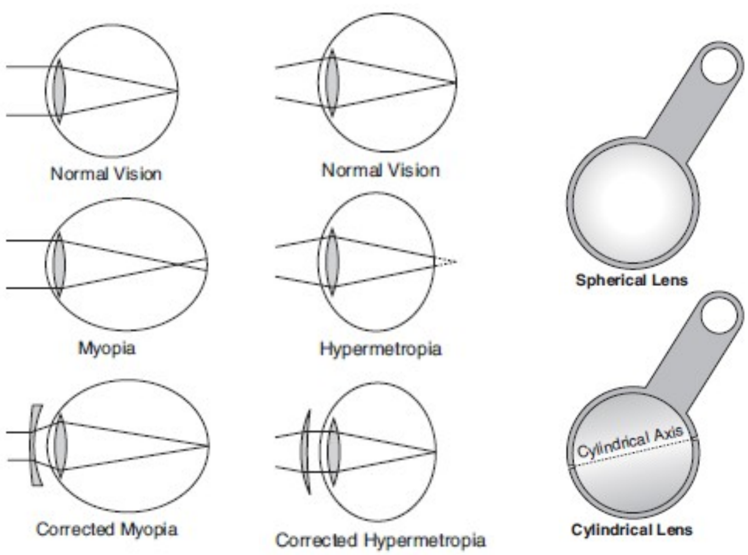


Figure 2: Vision defects and their corrections (left) and fixed focus lenses (right) from Pasco

[1] Figure 1 from url: http://brickellvision.com/wp-content/uploads/2014/10/eye-diagram.jpg

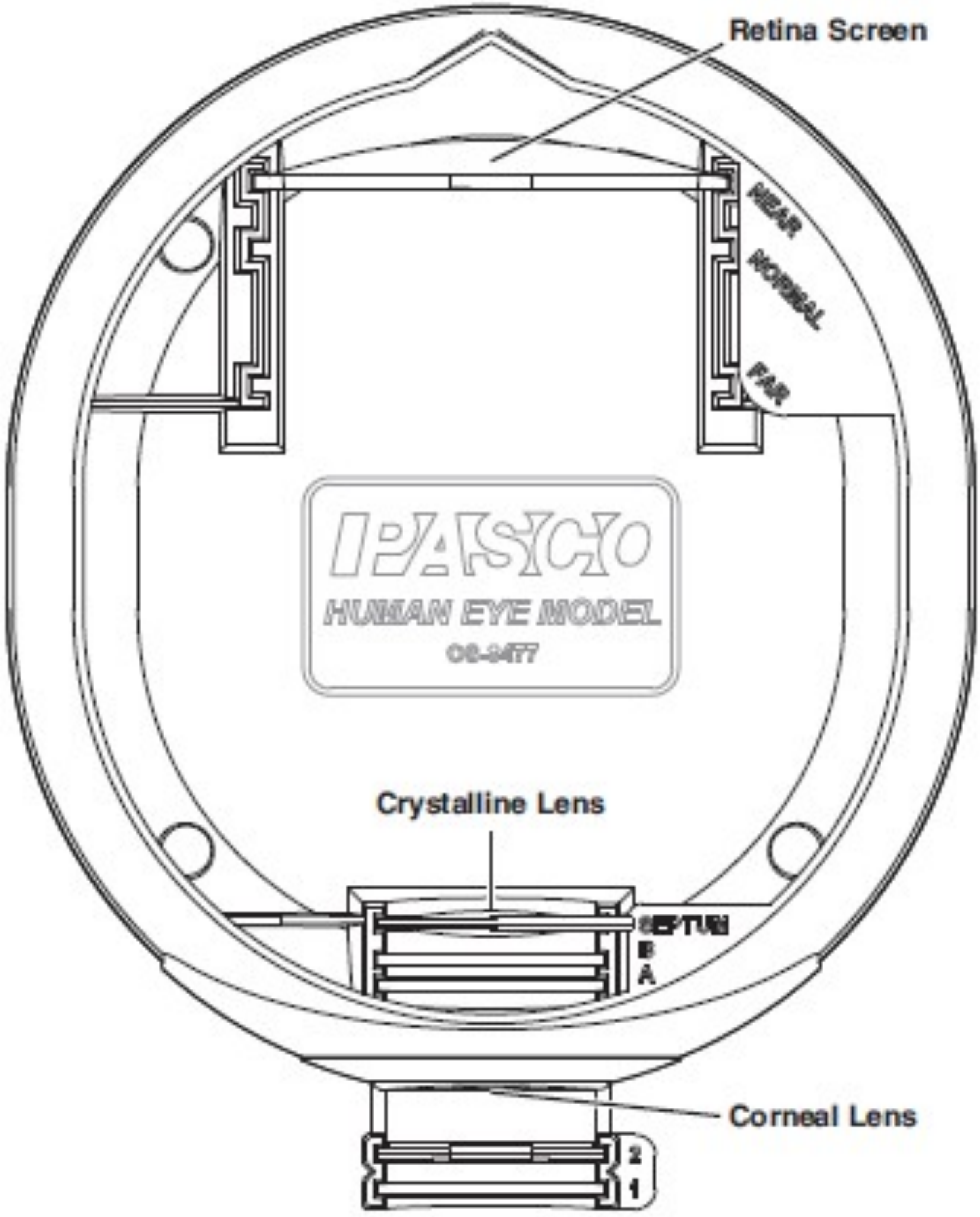


Figure 3: Human Eye Model Interior Labeled

PASCO Human Eye Model: The PASCO model of the human eye uses a sealed plastic tank that is roughly shaped like the horizontal cross-section of an eyeball. A plano-convex glass lens, permanently mounted on the front side of the eye model, acts as the cornea. The tank can be filled with water to model the aqueous humor and the vitreous humor. A replaceable lens behind the cornea models the crystalline lens of the eye. A screen, which is movable between the three slots, at the back of the eye model represents the retina [2]. See figure 3 for an annotated image of the top view of the apparatus.

Fixed-Focus Lenses: Fixed focus lenses with the focal length (in air) marked on the handle are provided. Crystalline lens in the slot SEPTUM can be replaced with spherical lenses to model the accommodation of the eye at various distances. The additional slots A and B behind cornea can be used to simulate the changing power of the eye. Slots 1 and 2 in front of the retina can be used to simulate eyeglass lenses for vision correction.

Retina: The adjustable curved screen can be placed in three positions (NORMAL, NEAR, and FAR) to simulate the vision of normal eye, near-sighted eye, and far-sighted eye. The circle represents the fovea and the hole represents the blind spot.

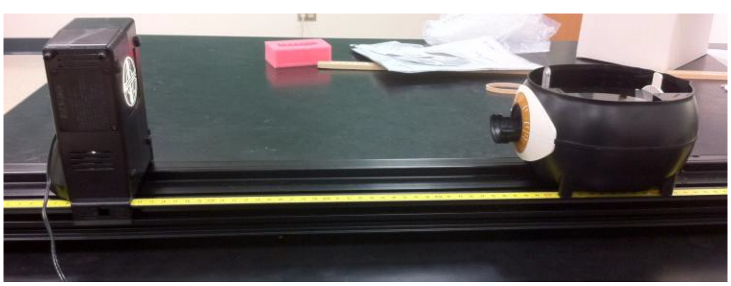
Part 1: Image Formation in the Eye

1. Place the human eye model on the rail with the light source as shown in Figure 4.

2. Do not fill the eye model with water yet. Put the retina screen in the middle slot marked NORMAL. Put the lens labeled +400 mm in SEPTUM.

3. Put your hand in front of the eye model about 50 cm from the cornea of the model. Use the flashlight to brightly illuminate the hand. Can you see any image on the retina screen? Move your hand up, down, left, and right. How does the image move?

4. Draw an asymmetric picture on a paper and hold it in front of the eye model (see Figure 5). Is the image of the picture on the retina inverted? Turn the picture upside down. How does the image look now? Sketch the retina image and draw the original picture next to the image.



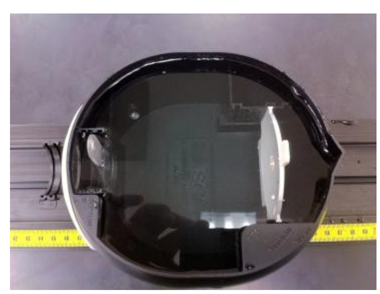


Figure 4: Setup for prelimary image formation side and top views

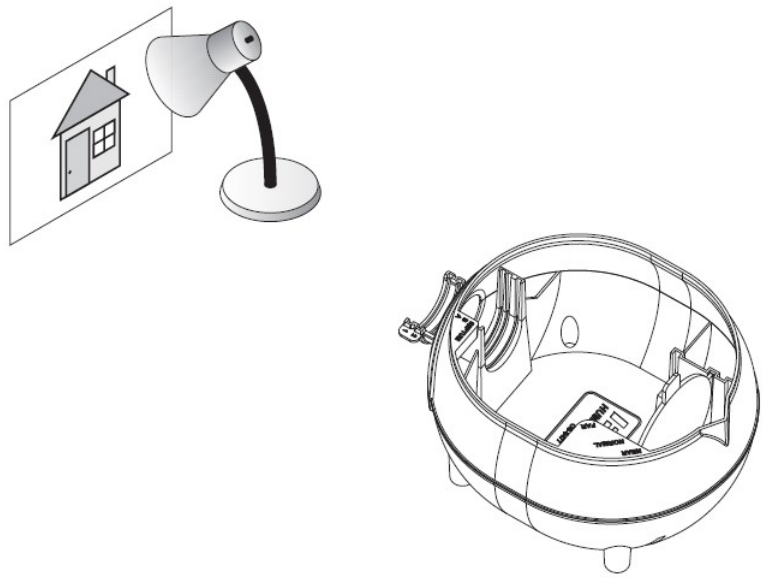


Figure 5: Example of an asymmetric picture for Step 4

Question:

1. The image on the retina is inverted, but why do you not see things upside down?

2. If you write letters on a piece of paper, and held it upside down in front of the eye, how would it look on the retina? Would you or anyone be able to read those letters easily?

Part 2: Accommodation

The muscles in the eye change the shape of the crystalline lens to change its focal length. This is called accommodation. Initially, you will model accommodation by varying the focal length of the crystalline lens using the adjustable focus lens. Latter, when the model is filled with water, accommodation is achieved by replacing the crystalline lens with fixed lenses of various focal lengths.

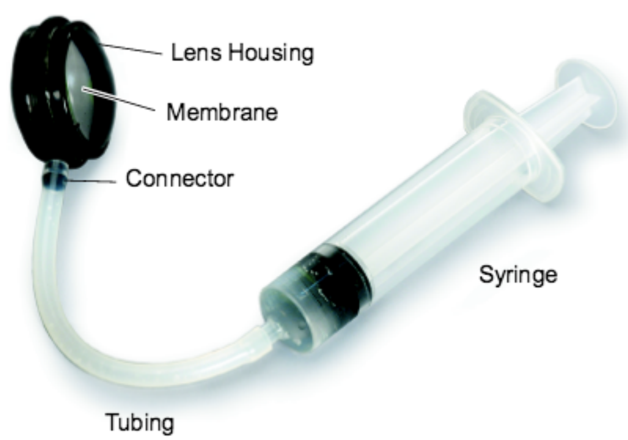


Figure 6: Adjustable lens

Note: If the adjustable focus length lens is not already filled with water, then please do so by consulting your instructor. While filling water, make sure to remove air bubbles by retracting the plunger in the syringe as many times as needed. Also make sure that the lens is not excessively pressurized. The syringe remains connected with this lens throughout the experiment.

1. Place the object (the illuminated light source) on the rails. Place the eye model about 25 cm from the object (i.e., d_0=25 cm from the top rim of the eye model to the light source). Replace the lens in the SEPTUM with the adjustable focal length lens. Can you see the image on the retina? Move the syringe plunger to adjust the focal length of the lens to form a clearest image possible. Is the lens concave (diverging) or convex (converging)?

Measure the image distance d_i (distance from the top rim of the eye to the retina). Calculate the effective focal length f of eye model using the thin lens equation:

$$Equation\ 1\colon \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Then, calculate the Power of the lens:

$$Equation\ 2\colon P = \frac{100}{f\,(in\ cm)} = P\ in\ units\ of\ diopter$$

2. Reposition the eye model now about 50 cm from the object (light source). Readjust the adjustable lens focal length by moving the plunger to form the clearest possible image. Measure d_0, d_i and calculate the focal length f. Did the focal length f decrease or increase? Compare the Power, P of the lens found in Step 1.

3. *+400 mm lens (with air in the eye model):* Replace the adjustable lens with the +400 mm lens in the SEPTUM. Adjust the position of the eye model (object distance) to form a clear image. Note this distance as d_0(+400 mm, air) = cm.

4. *+400 mm lens (with water in the eye model):* Fill the eye model with water until 1 to 2 cm from the top. Return the eye model to the same position as in Step 3. Is the image still in focus? Try to focus the image by changing the distance. Explain what you observe by considering the effect of vitreous humor and aqueous humor (modeled by water) on the focal length of the eye lens system.

5. *Near Point:* Place the eye model about 35 cm from the object (light source). Replace the +400 mm lens in the SEPTUM with the +62 mm lens. Is the image focused now? Move the eye model as close as possible to the light source while keeping the image focused. Describe the observed image on the retina. Measure the distance from the top of the eye model rim to the light source. Note this distance as the Near Point of the eye model equipped with the +62 mm lens: *N* (with +62 mm) = cm.

6. Measure the image distance d_i (from the top rim of the eye to the retina). Calculate the effective focal length f of the eye model system using Equation 1.

7. Add the +400 mm lens in slot B. With this lens you can increase the ability of the model eye to focus on a near object. This combination of +62 mm and +400 mm lens results in a different focal length for the crystalline lens of the eye model. Find out how close the model eye can focus now.

8. Replace the +62 mm lens in the SEPTUM with a +120 mm lens. Find out the new focal length of the model eye. Based on these observations explain what the human eye does to change the focal length of the crystalline lens.

9. *Far Vision Lens:* Remove both the lenses in model. Place the +62 mm lens in the SEPTUM. Carry the eye model to the printer area and hold the model so that it is looking towards the room entrance. Open the main door and let a team member (distant object) stand about 1m outside the entrance. Find out if the image on the retina is in focus or not. Replace the lens with a different one and find the lens that forms a clear image on the retina. This is the ***far vision lens***. Record its focal length (see the handle of the lens).

   Calculate the effective focal length of the eye model.

10. *Cataracts:* The crystalline lens is surgically removed in one type of treatment of cataracts. To simulate this remove the crystalline lens from the eye model and try to observe the image of a distant object on the retina. Can an eye without crystalline lens focus on a distant object?

    a. Place the +400 mm lens in slot 1 as an eyeglass lens. Is the vision of the model eye clear now? Place the eye model to look at a nearby object (light source). Adjust the distance and try if the object can be seen clearly.

    b. Replace the +400 mm lens with +120 mm lens in slot 1. Adjust the distance and find out if a clear image can be seen now.

Questions

1. When an eye changes accommodation from a distance object to a near object, does the curvature of the crystalline lens decrease or increase?

2. Does the eye’s range of accommodation change with age? Explain.

3. What is the modern treatment for cataracts as compared to the old method of surgical removal of the crystalline lens (such as in Step 10)?

Part 3: Farsightedness

In the case of farsightedness (hypermetropia), the eyeball is shorter than normal eye and the image is formed behind the retina.

1. Place the normal vision lens +62 mm in the SEPTUM and set the retina to NORMAL position. Adjust the eye model such that it is in near focus distance (*N* in Step 5 in Part 2) to the object (light source). Move the retina to the FAR slot. Record the observations. This is similar to how a farsighted person sees a near object.

2. Correct the farsightedness using an eyeglass lens in Slot 1. Identify the lens that needs to be in Slot 1 to focus the image on retina. Record the focal length of the lens.

3. Calculate the power of the eyeglass lens that works for the model eye using Eq. 2.

4. Rotate the eyeglasses lens to see if it affects the image.

Questions

1. Does a high power lens have a longer or shorter focal length?

2. Between the +62 mm and +400 mm lenses, which one has more curvature?

3. In real eyeglasses, each lens has one convex and one concave surface. To correct for farsightedness, which surface needs to be more curved?

Part 4: Nearsightedness

In the case of nearsightedness, the person has a longer than normal eye ball and the image is formed in front of the retina.

1. Place the normal vision lens +62 mm in the SEPTUM and set the retina to NORMAL position. Adjust the eye model such that it is in near focus distance (*N* in Step 5 in Part 2) to the object (light source).

2. Move the retina to the NEAR slot. Describe the observations about the image.

3. Correct the nearsightedness (myopia) using eyeglass lens in Slot 1. Identify the lens that needs to be in Slot 1 to focus the image on retina. Record the focal length of the lens.

4. Calculate the power of the eyeglass lens that works for the model eye using Eq. 2.

5. Rotate the eyeglass lens to see if it affects the image.

6. Remove the eyeglass lens. Readjust the distance between the model eye and the light source so that the image is in focus. Compare this object distance with the distance found in Step 1. Are these two the same? Explain.

7. Place the model eye to view a distant object (such as a computer screen on the other side of the room). Give a description of the image. Replace the lens in SEPTUM with the

far vision lens found in the Step 8 of Part 2. Is the image in focus? This is similar to how a nearsighted person sees a far-away object.

8. The lens currently in the SEPTUM represents the crystalline lens in the most relaxed state of the model eye.

Questions

1. Can an eye compensate for myopia by accommodation?
2. In the eye model, the slot marked as NEAR is farthest from the lens and the slot marked as FAR is nearest to the lens. What does the word FAR refer to?

References

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