Optics of the Human Eye

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.

Horizontal Cross Section of the Human Eye

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. Can you see an image on the retina screen? Move your hand up, down, left, and right. How does the image move?

(Go to Questions Part 1)

Part 2: Accommodation
In the process of accommodation, muscles in the eye change the shape of the crystalline lens to change its focal length. *Accommodation in the eye model is simulated by changing the lens or lenses that represent the crystalline lens.*

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 35 cm from the light source, with the eye looking directly at the illuminated screen. Can you see the image on the retina?
Move the eye model further away from the object until the image is in focus. Note the position of the eye model so you can return it to the same place after you fill it with water.
2. Fill the eye model with water to within 1 or 2 cm of the top. Return it to the same position as in step 1. Is the image still in focus?

Try changing the distance; can you get it to focus? Explain.

What effect do the aqueous and vitreous humors (modeled by the water) have on the focal length of the eye's lens system?

3. Place the eye model about 35 cm from the light source. Replace the +400 mm lens in the SEPTUM slot with the +62 mm lens. Is the image in focus now?

Move the eye model as close as possible to the light source while keeping the image in focus. Describe the image on the retina screen.

4. 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, which 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.

5. 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 the image distance (*i*), from the model's rim to the handle of the retina. Calculate the total *effective* focal length (*f*) of the two-lens system using the thin lens formula:

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

f_{eff}= _____

6. 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. How close can the eye focus now?
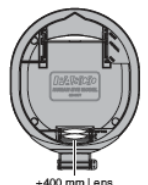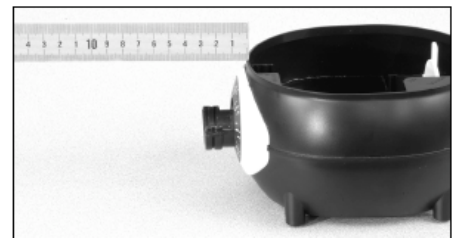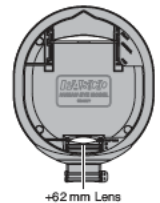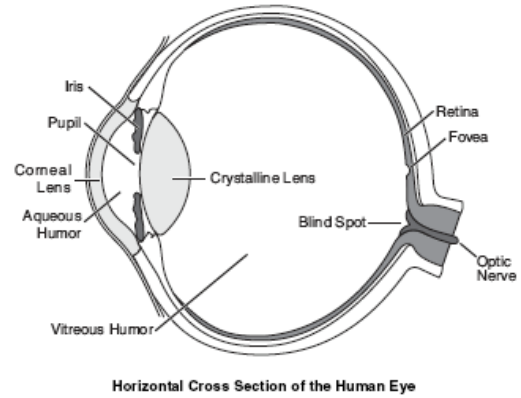
7. Keep the +400 mm lens in slot B and replace the lens in the SEPTUM slot with the +120 mm lens. At what distance does the model eye focus now? What does a real human eye do to change the focal length of its crystalline lens?

8. Remove both lenses and place the +62 mm lens in the SEPTUM slot. Adjust the eye-source distance to the "near point" distance for this lens (which you found in step 4) so that the image is in focus. While looking at the image, place the round pupil in slot A. What changes occur in the brightness and clarity of the image?

Move the light source several centimeters closer to the eye model. Is the image still in focus?

Remove the pupil and observe the change in clarity of the image. Both with and without the pupil, how much can you change the eye-source distance and still have a sharp image?
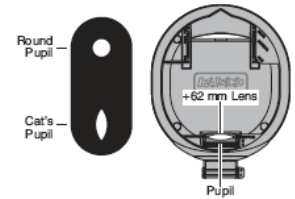
9. Position the eye model (with pupil removed) so that it is looking towards a *distant* object (try pointing it towards the outside). Is the image on the retina in focus? Replace the lens in the SEPTUM slot with one that makes a clear image of the distant object; this is the **farvision lens**. Record the focal length marked on the handle of the lens (use masking tape).

10. Calculate the total *effective* focal length of the lens system, as you did in step 5. What value should you use as the object distance for *far* vision? How do you enter that value into a calculator? (Hint: as the object distance, o, increases towards infinity, the inverse of the object distance, $1/o$, decreases towards zero.)

11. One treatment for cataracts is to surgically remove the crystalline lens. Remove the crystalline lens from the eye model and observe the image of the distant object on the retina. Can an unaided eye without a crystalline lens focus on distant objects?

Place the +400 mm lens in slot 1 to act as an eyeglasses lens. Does this restore clear vision?

Turn the eye model to look at the nearby light source. Can you adjust the near object distance to form a clear image?

Replace the eyeglasses lens in slot 1 with the +120 mm lens. Now can you adjust the object distance to form a clear image?

(Go to Questions Part 2)

Part 3: Far-sightedness (Hypermetropia)
A person affected by hypermetropia has a shorter-than-normal eye ball, 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 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.
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.

Decrease the pupil size by placing the round pupil in slot A. What happens to the clarity of the image? Remove the pupil.

3. Turn the eye model to look at the distant object, and describe the image. Does a far-sighted person have trouble seeing distant objects? Why was it not necessary to change the lens to look far away?

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. Record the focal length of this lens.
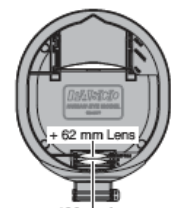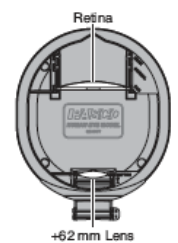
Rotate the eyeglasses lens in the slot. Does this affect the image on the retina?

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*. What is the power of the eyeglasses lens that you selected for the model eye?

6. Make sure that the image is still in focus. Remove the eyeglasses. Add the +120 mm lens in slot B to simulate what happens when the crystalline lens increases its power by accommodation. Does the image become sharper? This shows that the eye can compensate for hypermetropia if it can accommodate sufficiently.

(Go to Questions Part 3)

Part 4: Near-sightedness (Myopia)
A person affected by myopia has a longer-than-normal eye ball, 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 to normal, near vision (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.
2. Move the retina screen to the back slot, labeled NEAR. Describe what happens to the image. Decrease the pupil size by placing the round pupil in slot A. What happens to the clarity of the image? Remove the pupil.

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. Does rotating the eyeglasses lens in the slot affect the image?

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?

5. Turn the eye model to look at the distant object. Describe the image. Replace the lens in the SEPTUM slot with the normal far-vision lens.
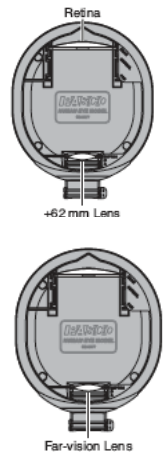
Is the image in focus? This is what a near-sighted person sees when trying to look at a far-away object.

The lens in the SEPTUM slot represents the crystalline lens in its most relaxed state, with its longest-possible focal length. Can an eye compensate for myopia by accommodation?

(Go to Questions Part 4)

Part 5: 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.

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?
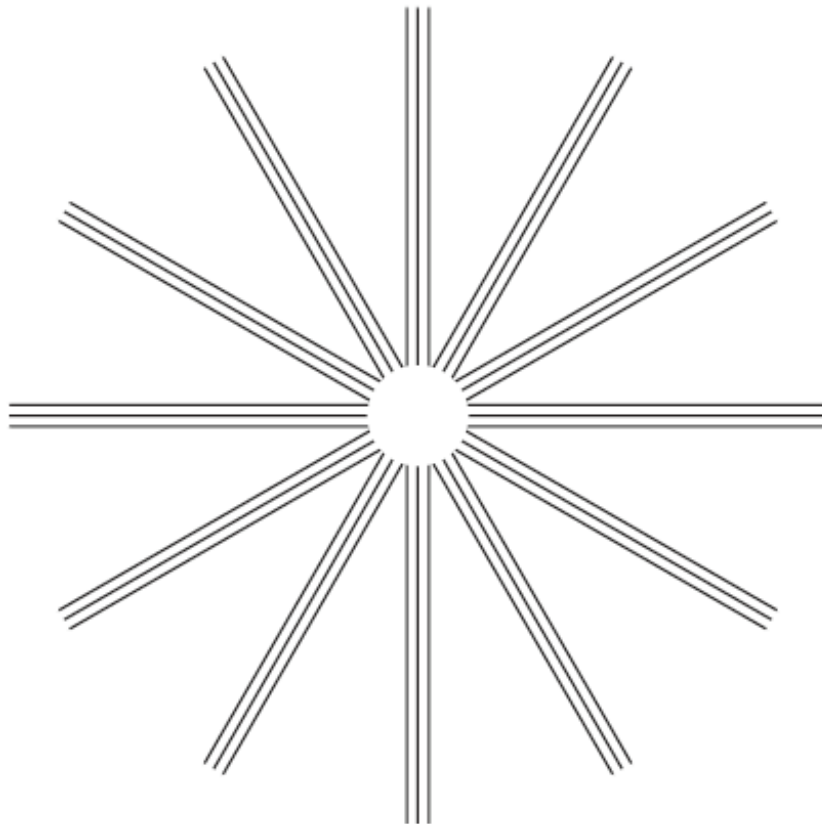
Astigmatism Chart

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.

2. Set the eye model to normal, near vision (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.

3. 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.

4. 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.

5. 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?
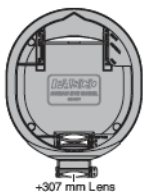
6. An eye can have more than one defect. Make the eye model have both astigmatism and hypermetropia (far-sightedness) by moving the retina screen to the FAR slot. Which additional eyeglasses lens do you have to put in slot 2 to bring the image back in focus?

(Go to Questions Part 5)

Part 6: Blind Spot
The blind spot is the small area on the retina where the optic nerve is attached. There are no rods or cones in the blind spot so it is insensitive to light.

Procedure
1. Cover your left eye and look at the figure below *with only your right eye*. Hold the paper at arm's length and stare at the plus sign with your right eye. To the right, in your peripheral vision, you should be able to see the dot. Do not look directly at the dot; stare at the plus sign as you slowly move the paper closer to your eye. At a distance of about 30 cm, does the dot disappear? Keep moving the paper closer. Does the dot re-appear?
2. What you "see" due to the blind spot is not a hole in the image, but an area where your brain fills in the missing details. Repeat the exercise with the figure below and adjust the distance so that the dot disappears. Do you see a white spot where the dot should be, or do the lines appear to intersect? Try making your own patterns.

You will find that your brain is very good at filling in (making up) the missing details. Try different colors.
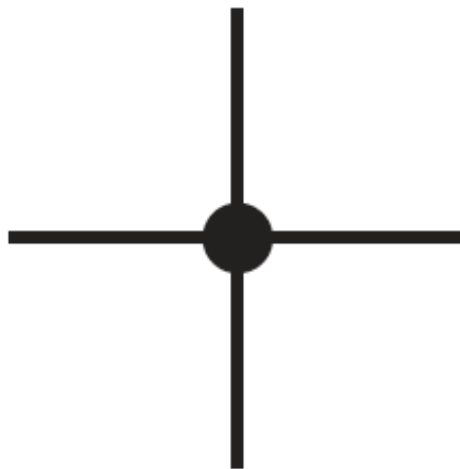
3. Set the eye model to normal, near vision (put the +62 mm lens in the SEPTUM slot, remove other lenses, and put the retina screen in the NORMAL position).
4. Make a copy of the above figure on a separate sheet of paper. Hold it about 30 cm from the front of the eye model and shine a desk lamp on the paper. Do you see an image of the figure in the eye model?

Adjust the object distance so that the image is in focus.
The blind spot of the model eye is represented by a hole in the retina screen. Can you adjust the position of the paper so that image of the small plus sign appears near the center of the retina and the dot falls on the blind spot?
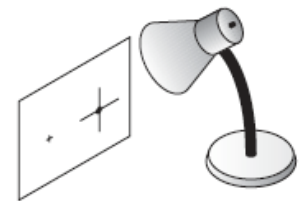
Make a sketch of the retina screen and the image on it. Which part of the paper does the eye model appear to be looking directly at?

Questions

Part One: Images Formed by the Eye
1. Since the image on the retina is inverted, why do we not see things upside down?

Part Two: Accomodation
1. In a real human eye, accommodation is accomplished by muscles that change the curvature of the crystalline lens. When an eye changes accommodation from a distant object to a near object, does the curvature of the crystalline lens increase or decrease? Why?

2. Why does the eye's range of accommodation decrease with age?

3. In part 2, step 11, you showed that, with the aid of eyeglasses, it is possible to focus an image after the crystalline lens has been removed. Is this an ideal solution for cataract patients? Explain. (Hint: which lens is responsible for accommodation? What would a person without crystalline lenses need to do to clearly see objects at different distances?)

How do modern cataract treatments improve upon this older surgical technique?

Part Three: Far-sightedness
1. Why did reducing the pupil size make the image clearer?

Would a person with hypermetropia see better in bright light or in dim light? Why?

2. Does a strong lens (high power) have a long or short focal length? Why?

What are the power and focal length of a thin, flat piece of glass with no curvature?

Part Four: Near-sightedness
1. Why did reducing the pupil size make the image clearer? Would a person with myopia see better in bright light or in dim light? Why?

2. To correct myopia, is it necessary to move the image formed by the eye closer to or farther from the eye's lens system? Does this require a convergent or divergent lens? Does this corrective lens add to or subtract from the light-bending power of the eye's lens system? Is the curvature of this lens concave or convex?

Part Five: Astigmatism
1. Why does rotating the corrective lens for astigmatism affect the image, but rotating a corrective lens for hypermetropia or myopia does not?

2. What test could you do to find out if a person's eyeglasses had a correction for astigmatism?

3. Does anyone in your lab group wear glasses that correct astigmatism? How could you test their glasses to see?

Part Six: Blind Spot
1. In order to repeat the blind-spot exercise in step 1 with your *left eye*, what do you have to do differently?

2. Try repeating the blind-spot exercise, but look at the image with both eyes. Why does it not work?

3. Does the screen in the model eye represent the retina of a left eye or a right eye? Explain.