Lab 5
Image Formation in the Human Eye

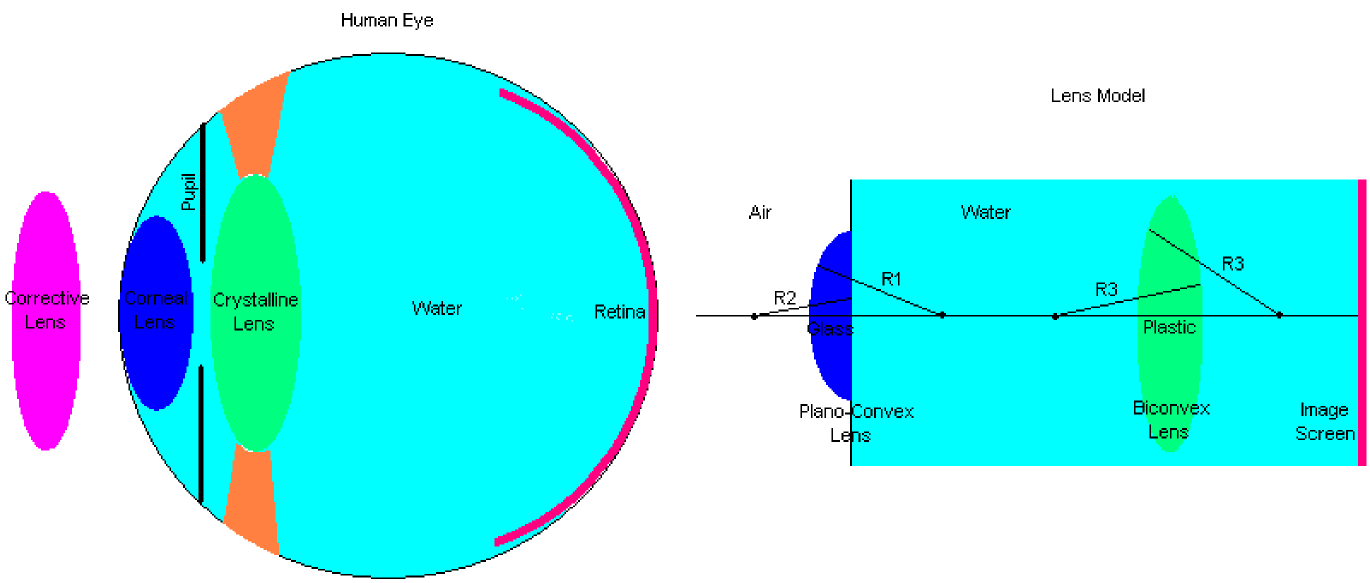
Learning Goals:

- To understand how lenses form images on the retina of the eye.
- To understand what other factors affect the quality of the image on the retina.

Apparatus

Instrument	Instrumental error	Instrumental resolution
Human Eye Model, Water, Light source, Flashlight		
Corneal lens (140 mm); Crystalline & Corrective six lens set	±1%	1 mm
Calipers	±1%	1 mm
Ruler	±1%	1 mm

Last lab, we witnessed how lenses (and combinations of lenses) refracted light from objects to form images. Those scenarios were fairly simple because they involved only one lens (or two closely-spaced lenses) and could be described using the thin lens equation. The human eye is a similar yet more complicated example of this.



Your eye is actually a two-lens system involving your *corneal lens* and *crystalline lens*. You may also have a *corrective lens*, such as eye glasses or contact lenses. The corneal lens is a *plano-convex lens* (convex on one side, flat on the other) with air to its left and water to its right (as drawn in the figure below). The crystalline lens is a *biconvex lens* (like last lab) and is surrounded on both sides by water. These lenses work together to form images on your *retina*, which is the “screen” at the back of your eye.

To solve this system for image formation, it will take several steps and we will need more than just the thin lens equation. The way to approach this problem is to place an object and determine image distance due to one lens, and use that image as the object for the next lens. The complications arise because the corneal lens is plano-convex and has different media on both sides. Also, because the biconvex crystalline lens is surrounded by water rather than air, its focal length is different from its listed value and must be recalculated. Since we are recalculating focal lengths and analyzing complex lenses, we must examine a new characteristic of a lens: its *radius of curvature* ≡ **R**. In the lens model above, the radius of curvature for the surfaces of the lenses will be used in the equations we need to solve for image formation. We will need to follow these steps:

Step 1

Curved Surface of Plano-Convex

We must use this equation to determine images distance due to the first surface:

$$\textbf{(1)}\quad (\mathbf{n_{air}}/\mathbf{s_o}) + (\mathbf{n_{glass}}/\mathbf{s_i}) = (\mathbf{n_{glass}} - \mathbf{n_{air}})/\mathbf{R_1}$$

where

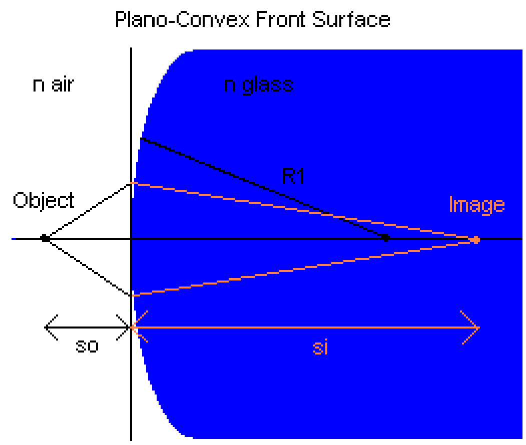
$\mathbf{n_{air}}$ ≡ "index of air" ≈ 1

$\mathbf{s_o}$ ≡ "object distance"

$\mathbf{n_{glass}}$ ≡ "index of glass" ≈ 1.524

$\mathbf{s_i}$ ≡ "image distance"

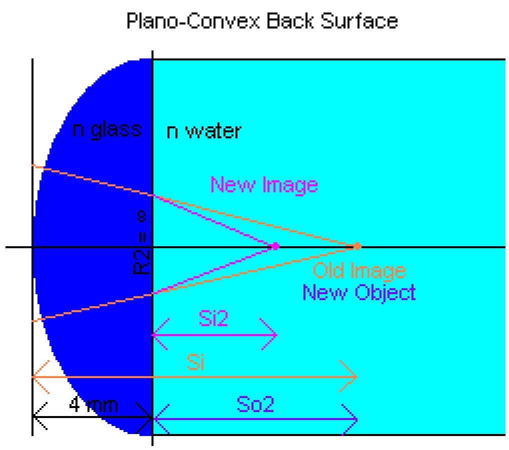
$\mathbf{R_1}$ ≡ "radius of curvature" ≈ 71 [mm]



Step 2

Flat Surface of Plano-Convex

Once you find the image distance from the curved side of the lens, it becomes the object for the flat side. Knowing $\mathbf{s_{o2}}$ is negative, the radius of the flat surface ≡ $\mathbf{R_2} = \infty$, and that we are moving from glass into water, equation **(1)** for the second surface:



$$\textbf{(2)}\qquad \mathbf{s_{i2}} = -(\mathbf{n_{water}}/\mathbf{n_{glass}})\mathbf{s_{o2}}$$

where

$\mathbf{s_{i2}}$ ≡ "new image distance"

$\mathbf{n_{water}}$ ≡ "index of water" ≈ 1.33

$\mathbf{n_{glass}}$ ≡ "index of glass" ≈ 1.524

$\mathbf{s_{o2}}$ ≡ "new object distance" = $\mathbf{s_i}$-4 [mm]

Step 3

Biconvex Lens Focal Length in Water

The listed focal length is the focal length of the lens in air. We need to calculate its correct focal length for when it is surrounded by water. We can first find its radius of curvature with:

$$\textbf{(3)}\qquad (1/\mathbf{f_{medium}}) = [(\mathbf{n_{plastic}}/\mathbf{n_{medium}})-1](2/\mathbf{R_3})$$

where

$\mathbf{f_{medium}}$ ≡ "lens focal length in medium"

$\mathbf{n_{plastic}}$ ≡ "index of plastic lens" ≈ 1.58

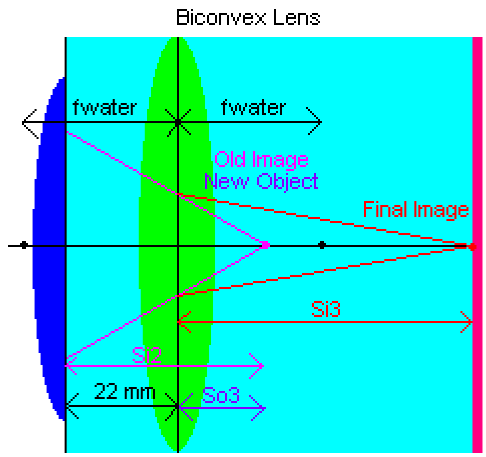
$\mathbf{n_{medium}}$ ≡ "index of surrounding medium"

$\mathbf{R_3}$ ≡ "curvature radius of biconvex lens"

Solving equation **(3)** using the listed focal length ≡ $\mathbf{f_{air}}$, and the index of the surrounding medium ≡ $\mathbf{n_{medium}}$ ≡ $\mathbf{n_{air}}$ **=** 1, you may solve for the biconvex lens' radius of curvature $\mathbf{R_3}$. Then you can use equation **(3)** again, this time using the known $\mathbf{R_3}$ and the index of the surrounding water ≡ $\mathbf{n_{medium}}$ ≡ $\mathbf{n_{water}}$ = 1.33, to solve for the corrected focal length ≡ $\mathbf{f_{medium}}$ ≡ $\mathbf{f_{water}}$.

<u>Step 4</u>

Biconvex Lens Image Formation on Screen



The old image produced by the flat side of the plano-convex lens now becomes the new object for the biconvex lens. This last calculation is easy because we only need to use the thin lens equation with the new focal length we just calculated:

(4) $(1/\mathbf{f_{water}}) = (1/\mathbf{s_{o3}}) + (1/\mathbf{s_{i3}})$

where

$\mathbf{f_{water}}$ ≡ "focal length of biconvex lens in water"

$\mathbf{s_{o3}}$ ≡ "new object distance" = $\mathbf{s_{i2}}$-22 [mm]

$\mathbf{s_{i3}}$ ≡ "final image distance"

<u>Myopia and Hypermetropia</u>

Myopia (near-sightedness) and *Hypermetropia* (far-sightedness) are two of the most common vision defects in the human eye. As we have seen above, lenses in the eye project an image a specific distance to where it is seen on the retina. Myopia is the result of having an elongated eyeball, such that the image is formed before it reaches the retina, creating a blurry image of distant objects. Hypermetropia is a result of the opposite: a shortened eyeball, such that the image forms behind the retina, distorting close objects.

The corneal lens and crystalline lens together act like a single, convergent lens. Light entering the eye from an object passes through this lens system and forms an inverted, real image on the retina. The **effective focal length of the combination** of both these lenses can be calculated using the thin lens formula: $1/f = 1/i + 1/o$. The focal length of the corneal lens is not changed by the eye muscles. The eye focuses on objects at varying distances by the use of muscles to change the curvature and thus the focal length of the crystalline lens. This adjustment is called accommodation. In its most relaxed state, the crystalline lens has a long focal length, and the eye can focus the image of a distant object on the retina. The farthest distance at which the eye can accommodate is called the far point for distinct vision.

When muscles in the eye contract and squeeze the lens, the focal length shortens allowing the eye to focus on closer objects. The nearest distance at which the eye can accommodate is called the near point for distinct vision. A person who is near-sighted (myopia) has an eye ball that is too long, making the distance from the lens system to the retina too large. This causes the image of distant object to be formed in front of the retinal. The far point of the myopic eye is than infinity.

Eyeglasses that correct myopia have a divergent lens, which forms a **virtual** image of the distant object closer to the eye. A person who is far-sighted (Hypermetropia) has an eye ball that is too short, making the distance from the lens system to the retina too small. This causes the image of near object to be formed behind the retina. The near point of a Hypermetropic eye is greater than normal. Eyeglasses that correct Hypermetropia have a convergent lens which reduces the divergence of incoming waves.

The prescriptions of these lenses are usually expressed in term of the *optical power* of the lens ≡ **p**, which is expressed in the unit of *diopters* ≡ [1/meters].

(5) $\mathbf{p} = 1/\mathbf{f}$

where

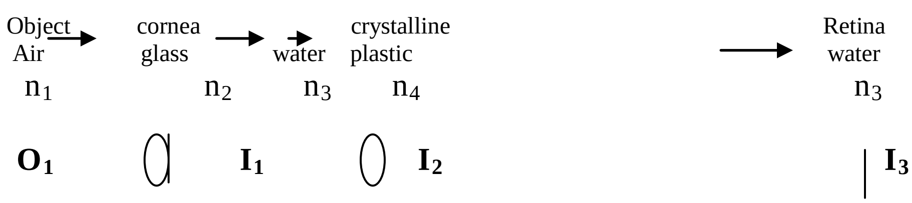
p ≡ "optical power"

f ≡ "focal length (in meters)"

Prelab:

1. A supplement (on the last page) follows with the solutions to problems presented in the procedures #1-#10. Use this supplement to complete the data table below with calculated or measured values as directed in the procedures.
2. Show that $n_1/o + n_2/i = (n_2-n_1)/R$ reduces to $i = n_{glass}R_1/(n_{glass} - 1)$ in the special case of an infinite object distance o and where $n_1 = 1$ for air and $n_2 = n_{glass}$.(n_1 is the medium air from which the light rays emerge and n_2 glass is another medium into which they enter, i is the image distance and o is the object distance). This equation will predict the distance from the corneal lens front curved surface for a sharp image i_1.
3. For the corneal lens $n_{glass} = 1.524$ and $R_1 = 7.10$ cm, calculate the image distance $\mathbf{i_1}$ formed by the curved surface. Indicate on the sketch the location of the image using a scaled distance from the corneal lens.
4. The image formed by the curved surface becomes the object for the flat surface (object #2). Indicate the position of Object #2. Indicate if Object #2 is in front of or behind the flat surface. Indicate if object distance #2 is positive or negative. Calculate the value of the object distance $\mathbf{o_2}$ given that the corneal lens is 0.40 cm thick.
5. Use the equation $i = -(n_3/n_2)o$, where n_2 is the medium glass (1.524) from which the light rays emerge and n_3 is another medium water (1.33) into which they enter, and calculate the image distance $\mathbf{i_2}$ of Image #2. The distance i_2 should be positive. This calculation will locate the distance from object #2 to the flat back surface of the corneal lens.
6. Add Image #2 to the sketch.
7. The number marked on the handle of the crystalline lens is its focal length in air. Since the lens is surrounded by water in the eye model, its focal length is not 120 mm. To predict where the crystalline lens will focus object #3 in water, its radius of curvature and effective focal length in water must be calculated. Use $1/f = [(n_{lens}/n_{medium})-1](2/R)$ to calculate the radius of curvature $\mathbf{R_2}$ of the surfaces of the 120mm lens, assuming that $n_{plastic} = 1.58$ and $n_{air} = 1.00$.
8. Calculate the focal length $\mathbf{f_3}$ of the crystalline lens in water. This will be used to predict where the image #3 formed by the crystalline lens will be formed in reference to it.
9. The image formed by the flat surface of the corneal lens (Image #2) becomes the object for the crystalline lens (Object #3). Record this object distance $\mathbf{o_3}$ as positive or negative. If the distance from the flat surface of the corneal lens to the center of the crystalline lens is 2.2cm, calculate $\mathbf{o_3}$.
10. Use the thin lens equation $1/f_3 = 1/i_3 + 1/o_3$ to calculate the image distance $\mathbf{i_3}$ of Image #3
11. Add Image #3 to the sketch.
12. Compare the measured distance from the crystalline lens to the retina screen with the calculated image distance i_3.
13. Explain why the equation $1/f = [(n_{lens}/n_{medium})-1](2/R)$ would not be accurate for the crystalline lens in a real human eye.

Supplement to Human Eye Model



When light travels from an object into the eye, three different optical media are involved. The light originates from object o_1 in the air of index $n_1 = 1.000$. The light then enters the corneal lens of index $n_2 = 1.524$ to form image i_1. The light leaving i_1 (now o_2) then enters the water of index $n_3 = 1.333$ to form image i_2. Then the light from i_2 (now o_3) enters the crystalline lens of index $n_4 = 1.586$ to form image i_3 through the water with index $n_3 = 1.33$ onto the retina.
When light rays travel in a medium with a higher index of refraction into a medium of a lower index of refraction, a negative sign is introduced. When the object is to the left of the interface, a negative is introduced.

When light travels from an object on the left of a lens through a lens to an image on the right of the lens, the sign of both the object distance and image distance is positive. If a change occurs in either location, a negative sign is introduced. When light travels from a medium with a higher index of refraction to s medium with a lower index of refraction, the sign of the image distance is positive. If a change occurs in the relative size of the indices, a negative sign is introduced.

Data Pre Lab (Human eye model) (Record in notebook): (see supplement on last page for answers, if necessary)

A. #2 Derivation of equation for image distance i is ________.
B. #3 Calculated value of image distance i is ______cm
C. #4 The position of Object #2 is ____________. Object #2 is …(circle one choice) *in front of,* *behind* …the flat surface. Object distance #2 is …(circle one choice) *positive, negative*.
    a. The calculated value of the object distance #2 is _______cm.
D. #5 The calculated image distance i_2 of Image #2 is ________cm.
E. #6 Image #2 added to sketch.
F. #7 The calculated value of R_2 is ______mm
G. #8 The calculated value of the focal length f_3 of the crystalline lens in water is _____mm
H. #9 The object distance o_3 with its sign is _________cm
I. #10 Calculated image distance i_3 is ________cm
J. #11 Image #3 added to sketch.
K. #12 The measured distance from the crystalline lens to the retina screen _______cm compared with the calculated image distance i_3 _____cm has a per cent difference of ____.
L. #13 Why is $1/f = [(n_{lens}/n_{medium})-1](2/R)$ not accurate for the human crystalline lens? ________.

Procedure: (Images formed in the eye)

1. Do **not** pour water into the eye model. Put the retina screen in the middle slot of the model marked normal. Put the 400 mm lens in the slot labeled septum; this is the crystalline lens.
2. Put your hand in front of the model, approximately 50 cm from the cornea. Use the flashlight to brightly illuminate your hand. Can you see the image on the retina screen? Move your hand up, down, left and right and notice how the image moves.

Data (record in notebook)

using 400 mm crystalline lens and 140 mm corneal lens

A. Description of image of hand on retina screen _______________________________.

Procedure

3. Position the eye model from a not too distant light source, with the eye looking directly at the source. Adjust the distance between the eye model and the object until the image is in focus. Record this distance in the data table in the notebook as object distance for eye model without water with 400 mm crystalline lens.
4. Fill the eye model with water to within 1 or 2 cm from the top. Set the distance between the eye model and object as in procedure 3. and check whether or not the image is still in focus.
5. **If** a clear focus **is** possible, record the distance between the eye model and object in the data table in the notebook. **If** a clear image **is not** possible, note that the 400mm crystalline lens will not accommodate the image.

Data (record in notebook)

using 400 mm crystalline lens and 140 mm corneal lens

B. If in focus, the distance between eye model (without water) and the object: ________cm.
C. If in focus, the distance between eye model (with water) and the object: ________cm.
D. If not in focus, will changing distance between object and eye model correct this? ____.
E. If not in focus, suspect effect of water in eye model on the focal length of the eye's lens system: Increases or Decreases it?________________.

Procedure: **Near vision**

using 62 mm crystalline lens and 140 mm corneal lens

6. Place the eye model with water approximately 35 cm from the light source and replace the 400mm crystalline lens in the septum slot with the 62mm crystalline lens.
7. Move the light source to focus the image on the eye model retina and then move the light source as **close as possible** to the eye model **with its image still in focus**. Describe in the notebook the quality and size of the image on the retinal screen with the eye model at this closest distance from the light source.
8. Measure the object distance **o** from the light source to the top front of the rim of the model. Record this distance in the notebook as the near point o_{NP} of the eye model with the 62mm crystalline lens.
9. Measure the image distance **i** from the rim of the model to the handle of the retina and record this in the notebook..
10. Calculate the effective focal length f of the combination of the 62 mm crystalline lens with the 140 mm corneal lens using the thin lens formula from the background section of this guide. Record this focal length in the notebook.

Data **Near vision** (record in note book)

using 62 mm crystalline lens and 140 mm corneal lens

F. Description of image with object at near point ___________________.

G. Near point distance **o** _________cm and corresponding image distance **i** _________cm .

H. Calculated effective focal length of 62mm and 140 mm crystalline lenses: f = _______cm.

Procedure: **Near vision**

using 62 mm and 400 mm crystalline lens and 140 mm corneal lens

11. To increase the ability of the model to focus on a close object, add the 400mm lens to slot B. This combination of the 62 mm and 400 mm lenses models a different focal length for the crystalline lens (the crystalline lenses now have a focal length of **54 mm**.).
12. Repeat procedures 7-10 then proceed to procedure 13.
13. Calculate the total focal length f of the lens system of 140mm, 62 mm and 400mm using the thin lens formula.

Data (record in note book) **Near vision**

using 62 mm and 400 mm crystalline lens and 140 mm corneal lens

I. Image description: ______________________. for 62 mm and 400mm lens combination.

J. Near point d_o ____________cm and image distance d_i __________cm for 140mm, 62 mm and 400mm lens combination.

K. Calculated effective focal length of 140mm, 62mm and 400mm lens combination f = _______cm.

Procedure: **Near vision**

using 120 mm and 400 mm crystalline lens and 140 mm corneal lens

14. Keep the 400mm lens in slot B, remove the 62mm crystalline lens from the septum slot and replace it with the 120mm crystalline lens. This combination models a different focal length for the crystalline lens. (the crystalline lenses now have an effective focal length of: **92 mm**.). Repeat procedures 7-10 with the different lens and then proceed to procedure 15.
15. Calculate the total effective focal length f of the lens system of 140 mm, 120 mm and 400mm using the thin lens formula.
16. Select the near vision optimum focal length f of the crystalline lens for seeing nearby objects.
17. Describe what a real human eye does to change the focal length of its crystalline lens to accomplish this.

Data **Near vision** (record in note book)

using 120 mm and 400mm crystalline lens and 140 mm corneal lens

L. Description of image with object at near point ___________________.

M. Near point distance **o** =_________cm and corresponding image distance **i** _________cm .

N. Calculated effective focal length of 140mm, 120mm and 400mm lens combination f = _____cm.

O. The optimum focal length of the **crystalline lenses** for near vision is (choose one of the following) 54mm, 62mm, 92mm. ___________.

P. To change its focal length to accommodate seeing a nearby object clearly, the crystalline lens of the human eye (choose one) becomes… *thicker, thinner*… in the center—(choose one) *decreasing, increasing* …its effective focal length,

Procedure : **Near vision**

Using 62 mm crystalline lens with pupil and 140 mm corneal lens

18. Remove both lenses and place the 62mm crystalline lens in the septum slot. Find the near point distance from the light source to the model as in procedure #7. While looking at the image, place the round pupil in slot A. Note the changes in the brightness and clarity of the image.
19. Move the light source several centimeters closer to the model. Note whether or not the image is still in focus.
20. Remove the pupil and observe the change in clarity of the image. Note the range in the distance from the light source to the model that still produces a sharp image
21. Predict the effect of replacing the round pupil with the cat's pupil. Test this and note the effect. Note which pupil, if any, helps in producing a sharp image of a nearby object.
22. Make a detailed drawing showing the object, image, round pupil and two lenses. Identify which lens models the 140 mm corneal lens and which lens models the 62 mm crystalline lens.

Data (record in notebook) **Near vision**

62 mm crystalline lens with pupil and 140 mm corneal lens

Q. Near point d_o ________cm for 62 mm crystalline lens without pupil.

R. With round pupil in slot A, the changes in the brightness and clarity of the image are:
____.

S. With the light source several centimeters closer to the model than the near point, the image is _____________ in focus.

T. With the pupil removed, the image ____________________and the range in the distance from the light source to the model that still produces a sharp image is from __________cm to ________cm.

U. The prediction of the effect of replacing the round pupil with the cat's pupil is ________and the observed effect is ____.

V. Suggested pupil for sharp image of nearby object: ___________________.

W. Drawing of procedure #22: ____.

Procedure : **far vision**

using crystalline lens and 140 mm corneal lens

23. With the 62mm crystalline lens in the septum slot, position the eye model (with pupil removed) so that it is looking toward a **distant** object. Note whether or not the image on the retina is in focus.
24. Replace the 62 mm crystalline lens in the septum slot with one that makes a clear image of the distant object. Record the focal length marked on the handle of this lens and identify this lens as the far vision lens. Indicate the value used for the object distance o and its reciprocal 1/o for far vision
25. Calculate the total effective focal length of the corneal and crystalline lens system using the thin lens formula.

Data **far vision** (record in notebook)

Testing crystalline lens for optimum far vision and 140 mm corneal lens

X. With the 62mm crystalline lens in the septum slot, the image on the retina (choose one) … *is, is not*… in focus when the eye model is looking toward a **distant** object.

Y. The focal length of the crystalline lens for optimum far vision is ____________cm.

Z. The object distance O used is _______cm and its reciprocal 1/O is __________cm^{-1} using optimum far vision crystalline lens.

AA. The total effective focal length of the 140mm corneal and optimum far vision crystalline lens system using the thin lens formula is ______cm.

Procedure : **far vision**

with 140 mm corneal lens but without crystalline lens

26. Remove the crystalline lens from the eye model and observe the image of the distant object on the retina from the corneal lens alone. Predict whether surgically removing the crystalline lens (a discontinued corrective procedure for cataracts) prevents the eye from focusing on distant objects without using a corrective lens. Test the prediction.
27. With the crystalline lens removed, place a 400 mm corrective lens in slot 1 to act as an eyeglass lens. Note whether or not clear distant vision is restored with this eyeglass.

Data **far vision** with 140 mm corneal lens but without crystalline lens
(record in notebook)

BB. The image of a distant object produced by the corneal lens alone is _______________ and the eye…(choose one) *does, does not* …need a corrective lens to produce a sharp image.

CC. The image of a distant object produced by the corneal lens and a 400mm corrective lens is… (choose one) *sharp, unclear*.

Procedure : **near vision**

with <u>140 mm corneal lens but without crystalline lens</u>

28. Turn the eye model to look at a nearby light source. Note whether or not the near object distance can be adjusted to form a clear image without the crystalline lens but with the 400 mm corrective lens eyeglass.
29. Replace the 400 mm corrective lens in slot 1 with the 120 mm corrective lens. Note whether or not the object distance can be adjusted to form a clear image with the 120 mm corrective lens.
30. The crystalline lens of the human eye accommodates to produce sharp images when viewing near objects and then for viewing distant objects. Predict the curvature of the crystalline lens when viewing near objects with the curvature of the crystalline lens when viewing distant objects.
31. Predict what is necessary to enable an eye without a crystalline lens to see sharp images of objects at different distances.

Data near vision <u>with 140 mm corneal lens but without crystalline lens</u>

(record in notebook)

DD. With an object near the eye model, the object distance… (choose one) *can, cannot* …be adjusted to form a clear image with the 400 mm corrective lens.

EE. With an object near the eye model, the object distance… (choose one) *can, cannot* …be adjusted to form a clear image with the 120 mm corrective lens.

FF. The curvature (thickness) of the crystalline lens when viewing near objects is (choose one)… *greater than, less than*…the curvature (thickness)of the crystalline lens when viewing distant objects.

GG. To enable an eye without a crystalline lens to see sharp images of objects at different distances, it is necessary ____.

Procedure (Hypermetropia) (retina too close to lens system; eye can't accommodate near objects) <u>Using 140 mm corneal lens and 62 mm crystalline lens</u>

32. Set the eye model for normal near vision (i.e., 140 mm corneal lens and 62 mm crystalline lens in the septum slot). Position a light source at the <u>near point</u> distance from the eye model so that the image is in focus on the retina in the normal position.
33. Move the retina to the slot labeled FAR to simulate a far-sighted person). Describe the image that a far-sighted person sees when looking at a near object.
34. Decrease the pupil size by placing the round pupil in slot A. Describe what happens to the clarity of the image. Explain the reason for the change in clarity. Remove the pupil.
35. Remove the near light source and have the model observe a <u>distant object</u> and note the clarity of the image. Explain why a different crystalline lens was not needed.
36. Again position a light source at the <u>near point</u> distance from the eye model with the retina in the FAR slot. Test different corrective lenses in slot 1 to correct for far-sightedness by selecting the lens that brings the light source into focus on the retina. Record the focal length of this lens.
37. Explain whether or not it is necessary to move the image formed by the eye's lens system closer to or father from the retina to correct for far-sightedness and note if the corrective lens adds or subtracts from the light bending power of the eye's lens system. Because each lens of real eyeglasses has one convex surface and one concave surface, predict which surface must be more curved to correct for hypermetropia
38. Test if rotating the corrective eyeglass lens in slot 1 affects the image on the retina.
39. Record the power of the corrective lens selected to adjust for far-sightedness. The power is the reciprocal of the focal length of the lens when measured in meters. Note the relationship between the power of a lens and its focal length.
40. With the image of the <u>near-by</u> object in focus, remove the corrective lens from slot 1 and insert the 120mm crystalline lens in slot B to simulate the accommodation of the 62mm crystalline lens to a different focal length. Note whether or not the image becomes sharper.

Data (**Hypermetropia**) (record in notebook) (retina too close to lens system; eye can't accommodate near objects) Using 140 mm corneal lens and 62 mm crystalline

HH. The image that a far-sighted person sees when looking at a near object is ______.

II. With the round pupil in slot A, the clarity of the image ____________________.

JJ. The clarity changes with the decrease in pupil size because ________________.

KK. When observing a distant object, the clarity of the image ___________________.

LL. A different crystalline lens was not needed because ________________________.

MM. The focal length of the corrective lens for far-sightedness is _________mm.

NN. It is necessary to move the image formed by the eye's lens system…(choose one) *closer to, farther from* …the lens system to correct for far-sightedness. The corrective lens …(choose one) *adds to, subtracts from* …the light bending power of the eye's lens system. The surface that must be more curved to correct for hypermetropia is the _________surface.

OO. Rotating the corrective eyeglass lens in the slot ____________________________.

PP. The power of the corrective lens for far-sightedness is _______diopters.

QQ. The stronger a lens (more power) the… (circle one) *smaller, larger*… its focal length.

RR. The image becomes (choose one) *less sharp, more sharp*…when the 120mm lens is inserted in slot B.

Procedure (**Myopia**) (retina too far from lens system; eye cannot accommodate distant objects)

Using 140 mm corneal lens and 62 mm crystalline lens

41. Remove all the lenses from the eye model and place the retina in the normal position. Insert the 62 mm crystalline lens in the septum and position a near light source so that its image is in focus on the retina. Note the near point.
42. Move the retina to the NEAR position (to simulate a near-sighted person) and move the model closer to the object, keeping the image in focus. Note the closer near point.
43. Decrease the size of the pupil by placing the round pupil in slot A. Note what happens to the clarity of the image. Remove the pupil.
44. Remove the 62 mm crystalline lens and replace it with the normal vision distance lens of 120 mm. Focus the model on a distant object and insert a corrective lens in slot one until the image of the distant object is brought into sharper focus. Record the corrective lens focal length for distant vision for a near-sighted person.
45. Explain whether or not it is necessary to move the image formed by the eye's lens system closer to or father from the lenses to correct for near-sightedness. Note for the myopic eye whether or not the distance between the eye and the image formed by the corrective lens is greater than or less than the distance between the eye and the object; also note whether or not the corrective lens adds or subtracts from the light bending power of the eye's lens system.
46. Because each lens of real eyeglasses has one convex surface and one concave surface, predict which surface must have a smaller radius of curvature to correct for myopia.

Data (**Myopia**) (retina too far from lens system; eye cannot accommodate distant objects)

Using 140 mm corneal lens and 62 mm crystalline lens

SS. The near point with the retina in the NORMAL position _________cm.

TT. The near point with the retina in the NEAR position _______________.. The distance from the light source to the eye model is …(choose one) *greater than*, *less than* …the normal near-point distance when the retina was in the normal position.

UU. The effect on the image of the round pupil in slot A ________.

Using 140 mm corneal lens and 120 mm crystalline lens

VV. The corrective lens focal length for distant vision for a near-sighted person is ______mm. and the power of the corrective lens for near-sightedness is _______diopters and rotating the corrective eyeglass lens in the slot ___________________________.

WW. It is necessary to move the image formed by the eye's lens system…(choose one) *closer to, farther from* …the lens system to correct for near-sightedness. The distance between the eye lenses and the image formed by these lenses is… (circle one) *greater than, less than* …the distance between the eye and the object. The correcting lens …(choose one) *adds to, subtracts from* …the light bending power of the eye's lens system. The surface that must have a shorter radius of curvature to correct for myopia is the__________________surface.

XX. One can conclude that an eye *cannot* accommodate for clear vision of distant object either because the retina is *too*… (circle one) *close to*, *far from*…the crystalline lens or because the eye is (circle one) …too far from or too close to …the object.

Supplement: PRELAB ANSWER KEY

First interface encountered by the light: The light travels from air through the curved surface of the corneal lens according to $n_1/o_1 + n_2/i_1 = (n_2 - n_1)/i_1$ where R_1 is the radius of curvature of the plano-convex corneal lens. The simple lens equation cannot be used because the light is not passing through a double convex thin lens. Substitute the values in the equation to solve for i_1 for the case when the object distance is much greater than the index of refraction for any particular unit of length specified by the radius R_1.

A

B

$1.000/\text{very large} + 1.524/i_1 = (1.524-1.000)/7.10$ cm. Then $I_1 = 20.6$ cm which is the distance into the corneal lens that the image would be if the lens were long enough to accommodate it. Actually the lens is only 0.40 cm thick.

C

Second interface encountered by the light: the light travels through the flat surface interface between the corneal lens and the water. Even though the light is traveling from left to right from the glass into the water (which introduces a negative sign), the object location O_2 is to the right of the flat glass/water interface. Because the index of water ($n_3 = 1.333$) is less than the index of glass ($n_2 = 1.524$), the image distance I_2 --formed by the flat surface as the light travels into the water from the left of the interface--is to the right of the glass-water interface in water, a negative sign is introduced: There are now two negative signs, making the image distance i_2 positive on the right of the glass interface.
Because $I_2 / O_2 = - n_3 / n_2$. and because O_2 is (20.6-0.4) cm away from the flat surface interface,
$I_2 / -20.2 = - 1.333 / 1.524$ or $I_2 = 17.7$ cm which is a positive distance indicating the image is on the right in the water.

D

Third interface encountered by the light: Because the crystalline lens is only 2.2 cm away from the corneal lens, the image i_2 (now o_3) is only 15.5 cm away from the crystalline lens to its right. The light from the corneal lens will travel to the right through the crystalline lens but the sign convention introduces a negative.

H

$o_3 = -15.5$ cm. The crystalline lens is a double convex plastic lens so the simple lens equation can be used. The crystalline lens is immersed in water not air so its focal length, given by the manufacturer measured in the air, must be corrected. To correct the 120 mm focal length use the equation
$1/f = [(n_4 - n_1)/(n_1)](2/R_2)$ or $1/120 = [(1.586 - 1.000)/(1.000)](2/R_2)$ so that its effective radius is $\mathbf{R_2} = 139$ mm. Solving for the corrected focal length for the plastic lens in water:

F

G

$1/f = [(n_4 - n_3)/(n_3)](2/R_2)$ or $1/f = [(1.586 - 1.333)/(1.333)](2/139)$ which corrects the crystalline lens focal length when in water to $\mathbf{f_3} = 370$ mm.
Now the simple lens equation can be used with the object o_3 distance as -15.5 cm:
$1/f = 1/o_3 + 1/i_3$ or $1/37.0 = 1/-15.5 + 1/I_3$ or $\mathbf{i_3} = 10.9$ cm. For a sharply focused image on the retina, the crystalline lens and the retina should be 10.9 cm apart.

I