The Eye

Objectives:

- Describe the basic process of image formation by the human eye and how it can be simulated in the laboratory.
- Know what measurements are necessary to quantitatively diagnose near-sightedness or far-sightedness.
- Locate the far points and near points of simulated ideal and myopic eyeballs.
- Describe how spectacle lenses can correct far-sightedness or near-sightedness.
- Calculate the power and type of spectacle lens required to correct a given simulated near-sighted eye. Observe its effect.
- Observe the effects of astigmatism and its correction with a cylindrical spectacle lens.
- Determine the depth-of-field of the simulated eyeball and how it depends on the diameter of an iris diaphragm near the lenses.
- Determine your own near point and far point with spectacles (if you wear them) and without spectacles. Calculate your required and actual prescriptions based on these measurements.

Introduction

Figure 1 shows the optics of the human eye. It behaves like a color TV camera with a variable focus lens. The eye is nearly spherical, so that it may be rotated easily in it socket. It is focused (accommodated) at different object distances by contraction of the ciliary muscles which changes the radius of curvature of the crystalline lens and thereby changes its focal length. The iris acts as a variable aperture to control the amount of light that reaches the retina. The light which forms an image on the retina stimulates electrical signals which travel along the optic nerve to the brain for interpretation of the image.

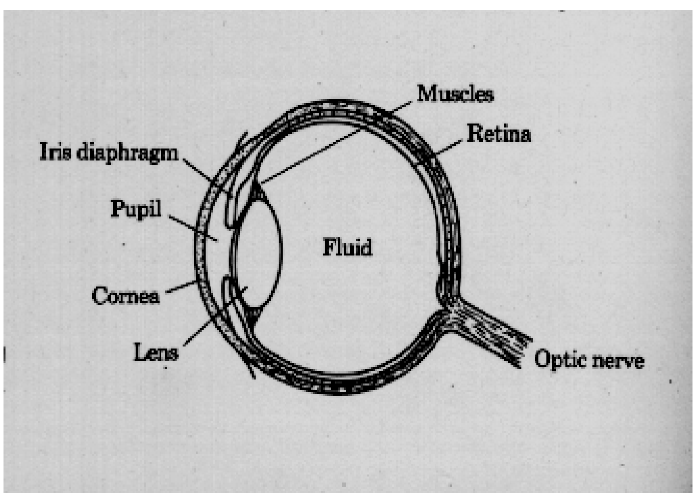

Fig. 1: The human eye

Optically, most of the refraction of light takes place at the front surface of the eye (the cornea) and the remainder takes place at the crystalline lens. The ciliary muscles can change the shape of the crystalline lens to focus the eye from its Far Point (the most distant object which can be seen clearly when the ciliary muscles are relaxed) to its Near Point (the nearest object which can be clearly seen when the ciliary muscles are contracted as much as possible). As mentioned above, the process of focusing on nearby objects is called accommodation.

For an idealized, so-called "normal" eye, the Far Point (FP) is infinity and the Near Point (NP) is about 25 cm. Very few persons have such "normal" eyes.

Simple defects of the eye include:

- having too long an eyeball, resulting in myopia or near-sightedness,
- having too short an eyeball, called hyperopia leading to far-sightedness,
- having a non-spherical surface, usually the cornea, giving rise to astigmatism.

Correction can be made for each of these defects by using a spectacle lens (eyeglasses) of the proper type and appropriate focal length placed in front of, and very close to, the eye.

Inadequate accommodation (ability to focus the eye for various distances) can be corrected by using bifocal or trifocal lenses, which have segments of different focal lengths, to provide two or three sharp viewing distances through the separate parts of the lens.

In this experiment you will work with an optical system which simulates that of the human eye, but which is larger in size and less messy to work with, as we will not use fluids.

Figure 2 shows the optical system that we shall use. Lens L_1 represents the refraction which takes place at the front surface (cornea) of the eye and lens L_2 represents the crystalline lens. You will have two lenses of different focal lengths to insert for L_2, one L_2 (far) for its behavior when viewing distant objects, and one L_2(near) for its behavior when viewing nearby objects. Remember that the crystalline lens of an actual eye can be accommodated for any value of focal length between those of L_2(far) and L_2(near).

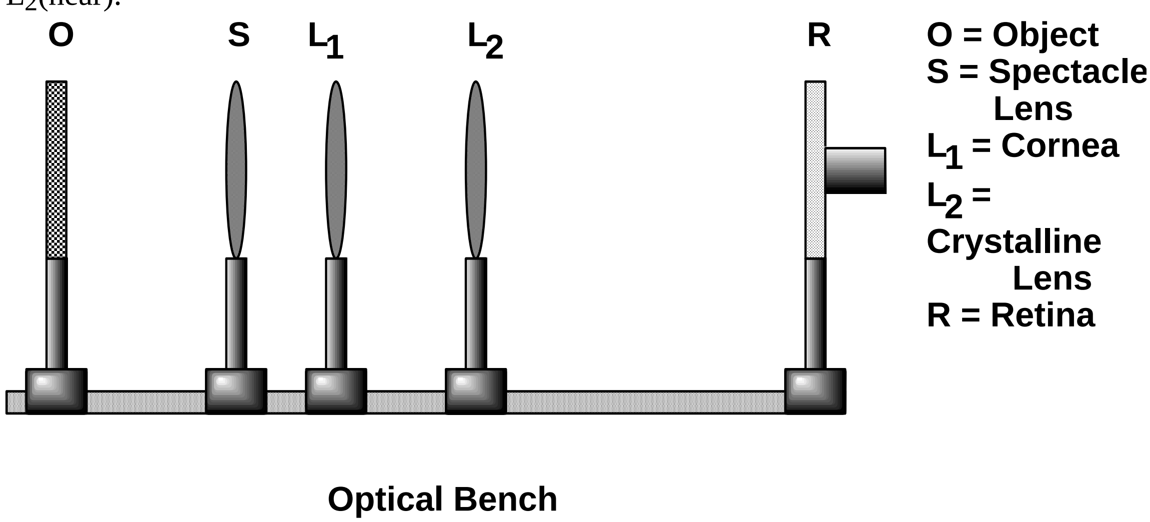

Fig. 2: Optical Equivalent of the Eye

Procedure

Note: All distances are measured from the cornea i.e. L_1.

The "Normal Eye"

a) Set up the optical system as shown in Figure 2 with L_2(far) placed close to L_1, and without the object on the optical bench. Adjust the position of the retina so that a sharp image is obtained for the most distant objects you can use. Look out the window at a distant building or tree or light. Record your estimate of the distance from L_1 to this object. Tighten all the mounts on the bench and measure the "length" of the eyeball from L_1 to R.

b) Substitute lens L_2(near) for L_2(far) and measure the actual near point, NP, of the system using the object on the bench. Repeat this measurement several times and record the near point values from L_1. **NOTE:** There will be a moderate range of object distances for which a clear image is obtained. This range is called the <u>depth of field</u> of the optical system.

c) From the range of values for NP, calculate the mean $\langle \mathrm{NP} \rangle = \frac{1}{n}\sum_{i=1}^{n} \mathrm{NP}_i$ and the standard deviation uncertainty in the mean $\sigma_m = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}\left(\mathrm{NP}_i - \langle \mathrm{NP} \rangle\right)^2}$. Here, n is the number of your measurements of the NP. These will provide the best estimate of the true value for NP and its uncertainty. Your instructor can show you how to do this with Kaleidagraph. A discussion of these expressions can be found in Chapter four of Taylor.

The "Nearsighted Eye"

a) Increase the length of the "eyeball" by 2.0 cm, by moving the retina (viewing screen) back.

b) Measure the actual near point along the optical bench (from L_1) several times. Determine the best value and its uncertainty.

c) Replace L_2 (near) by L_2(far) and measure the actual far point along the optical bench several times. Determine the best value for the far point and its uncertainty.

d) Calculate the proper focal length of a spectacle lens so that the system, including the spectacle lens will have a normal far point at infinity.

To do this, use the thin lens equation $\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$, where s is the object distance, s' the image distance, and f the focal length of the spectacle lens. In this application, s is the desired object distance, viz., infinity, s' = -FP as obtained in 2(c).
Convert the focal length obtained in this manner into the power of the lens as specified by optometrists, using the equation: P = 100/f(cm) diopters to specify the required spectacle lens. (Positive power values denote converging lenses and negative power values diverging lenses.)

e) Choose from the available lenses the one closest in power to the value you obtained in (d) and mount it very close to and in front of L_1.

f) Measure and record the far point and the near point of your system, including the spectacle lens.

g) Compare your measurements of near and far points with your expectations.

The "Astigmatic Eye"

a) Place the weak cylindrical lens L_3 in front of L_1 and L_2 (near), and examine the appearance of the image of the object consisting of several radial lines, as the object distance is varied, and then as the eye length is varied. (This is not the way the eye works but the effect on the image is the same.) The effect you are seeing is astigmatism. Sketch its appearance for several settings to show the range of possible appearances.

b) Mount the "matching" cylindrical lens L_4 in front of L_3 and rotate it in its mount until the astigmatism is corrected.

Measurement of own NP and FP.

a) without spectacles (glasses)

b) with spectacles, if you wear them

Depth of Field

Place the variable aperture near L_1 and observe the effect of its diameter on the "depth of field" (range of object distances producing a "sharp" image) near the near-point of the system used in "Normal Eye" (b). (Squinting can produce a somewhat similar effect.)

Report Inclusions

Your report should include:

1. a) sketch of optical system
   b) value of far point of normal system
   c) best value of near point of normal system and its uncertainty

2. a) best value of near point of myopic system and its uncertainty
   b) best value of far point of myopic system and its uncertainty
   c) calculation of f and P for spectacle lens
   d) values of far point and near point of system plus spectacle lens
   e) comparison with hoped-for result

3. a) sketches and description of "visual" effects of astigmatism
   b) description of manner and success of correction for astigmatism

4. Estimates of your own near points and far points

5. Description of effects of variable aperture on image obtained