OPTICS OF THE EYE

Objective

To study the optical properties of the human eye using a model. In this experiment you will observe the properties of a "normal eye" and you will also investigate the methods used to correct visual defects.

Apparatus: Eye model, set of lenses, meter stick, light source.

Discussion:

The Eye Model

Figure 1 shows a cross-section view of a human eye. Light enters through the cornea and passes to the retina, the light sensitive layer at the back of the eyeball. En route, the light passes through the liquid aqueous humor, the lens, and the gel-like vitreous humor. Most of the refraction takes place at the air-cornea interface, but some takes place at the other interfaces as well. The muscles surrounding the lens can deform the lens to change the shape of its surface and thus to changes its effective focal length.

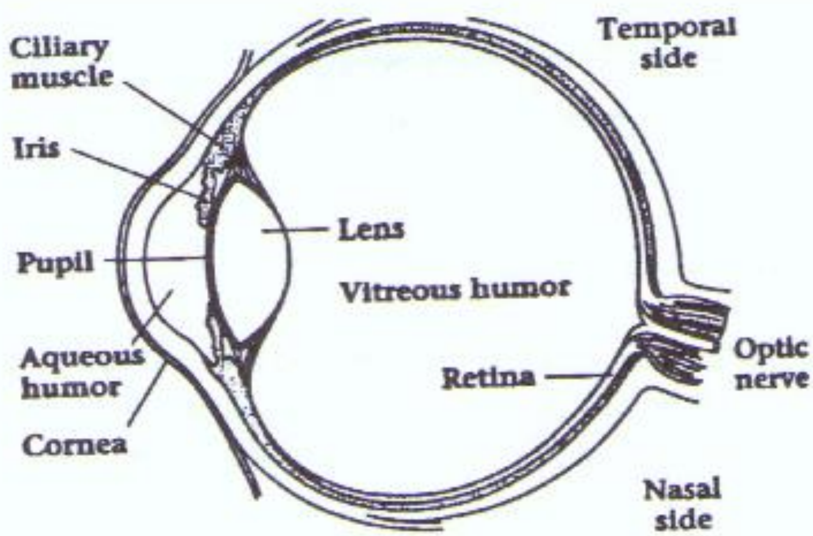


Figure 1. Cross section of a human eye viewed from above, showing the main optical elements.

The eye model (Fig. 2) consists of a metal tank shaped roughly like a horizontal section of the eyeball.* A window in one side of the tank is covered with a meniscus lens which serves as the cornea. The tank filled with water represents the eyeball and its aqueous and vitreous humors. An interchangeable crystalline lens L is mounted in a septum, which marks the boundary between the "humors". Two supports are provided for the insertion of additional lenses and a diaphragm. In front of the cornea are additional supports for spectacle lenses. The retina is represented by a circular white area on a removable curved screen which may be held in various positions by means of a series of grooves in the wall of the tank. The blind spot is represented by a black spot on the retina.

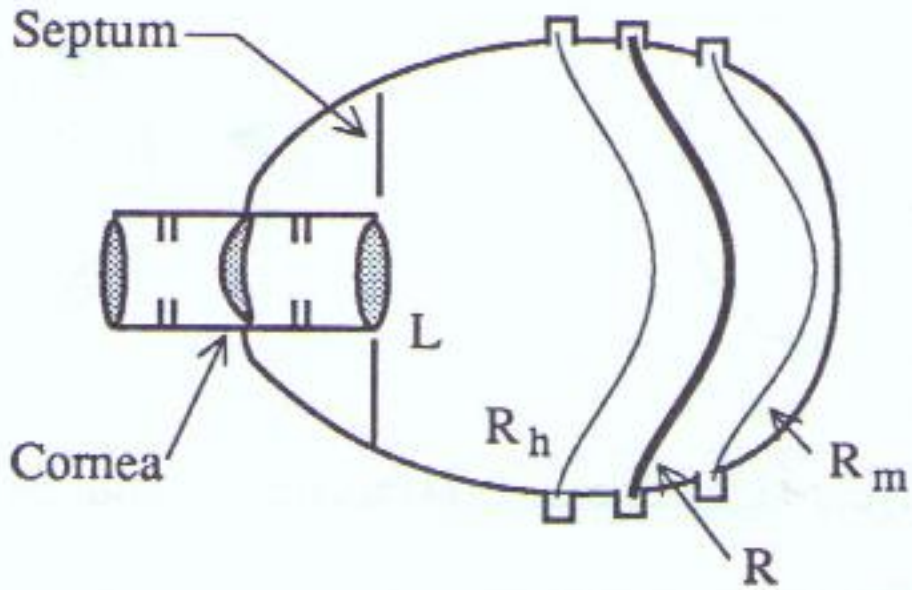


Figure 2. Plan view of the eye model.

A set of six different lenses, the kinds used by optometrists in ascertaining defects of the eye, is supplied with each eye model. The lenses are mounted in metal holders, with the handles on which are stamped the focal length (in diopters) and the kind of lens (positive or negative for convergent or divergent).

Visual Defects and their Corrections

Far-sightedness and Near-sightedness: Sometimes the focal length of the eye is too great for the retinal distance, causing the image of a nearby object to be formed back of the retina. In this case, only distant objects are imaged exactly on the retina. This condition is called far-sightedness (*hypermetropia*). Far-sightedness is corrected by a supplementary lens that is convergent, or positive. This situation is represented diagrammatically in Fig. 3.

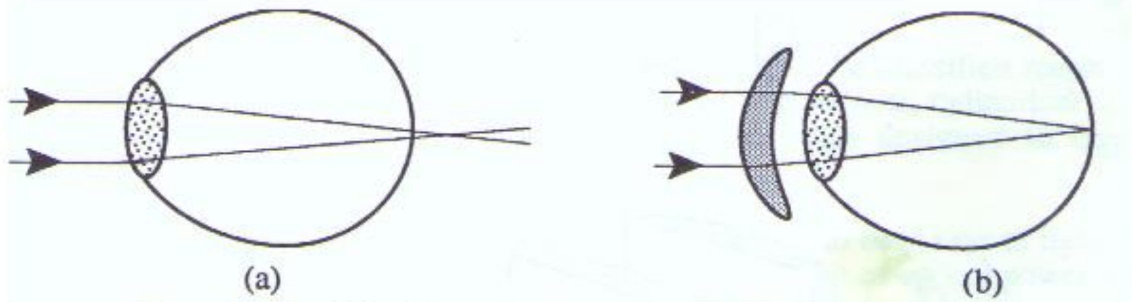


Figure 3. Far-sightedness. (a) Uncorrected and (b) corrected.

Near-sightedness, or myopia, is the result of a focal length too short (curvature too great) for the retinal distance, causing the image to be formed in front of the retina. Divergent, or negative, spectacle lenses are used to correct myopia as shown in Fig. 4.

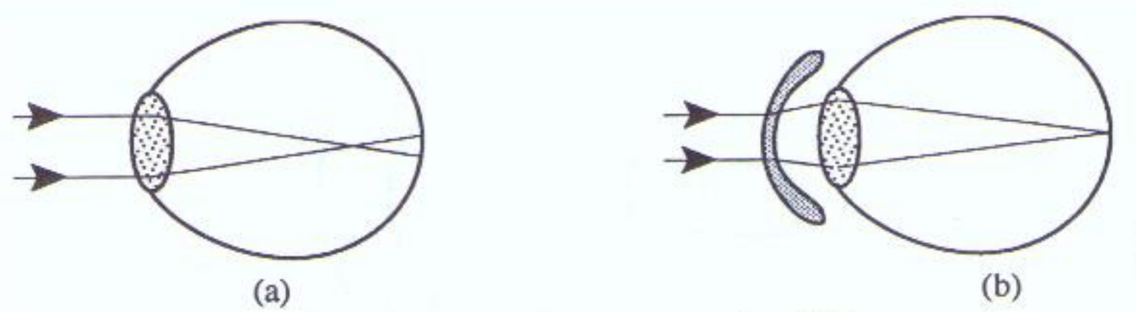


Figure 4. Near-sightedness. (a) Uncorrected and (b) corrected.

Astigmatism: Astigmatism is a defect of optical instruments, the effect of which is to image a point source of light as a short straight line instead of as a point. It results from a lack of symmetry of the optical system about the line of sight. In the case of the eye, astigmatism results from a lack of symmetry of the lens system about its axis, i. e., a departure from sphericity in some of the refracting surfaces.

The result of astigmatism is that the image is not formed sharply anywhere, but there are two positions of best definition. At one of these, only lines in a certain direction are sharply defined (or focused), while at the other position only lines at right angles to that direction are sharply focused. In effect, an astigmatic lens has two unequal focal lengths for lines at right angles to each other. The difference between these focal lengths is called the astigmatic difference. Astigmatism and its correction are illustrated in Fig. 5 in which L represents a rectangular section cut out of the center of a non-symmetric plano-convex lens.

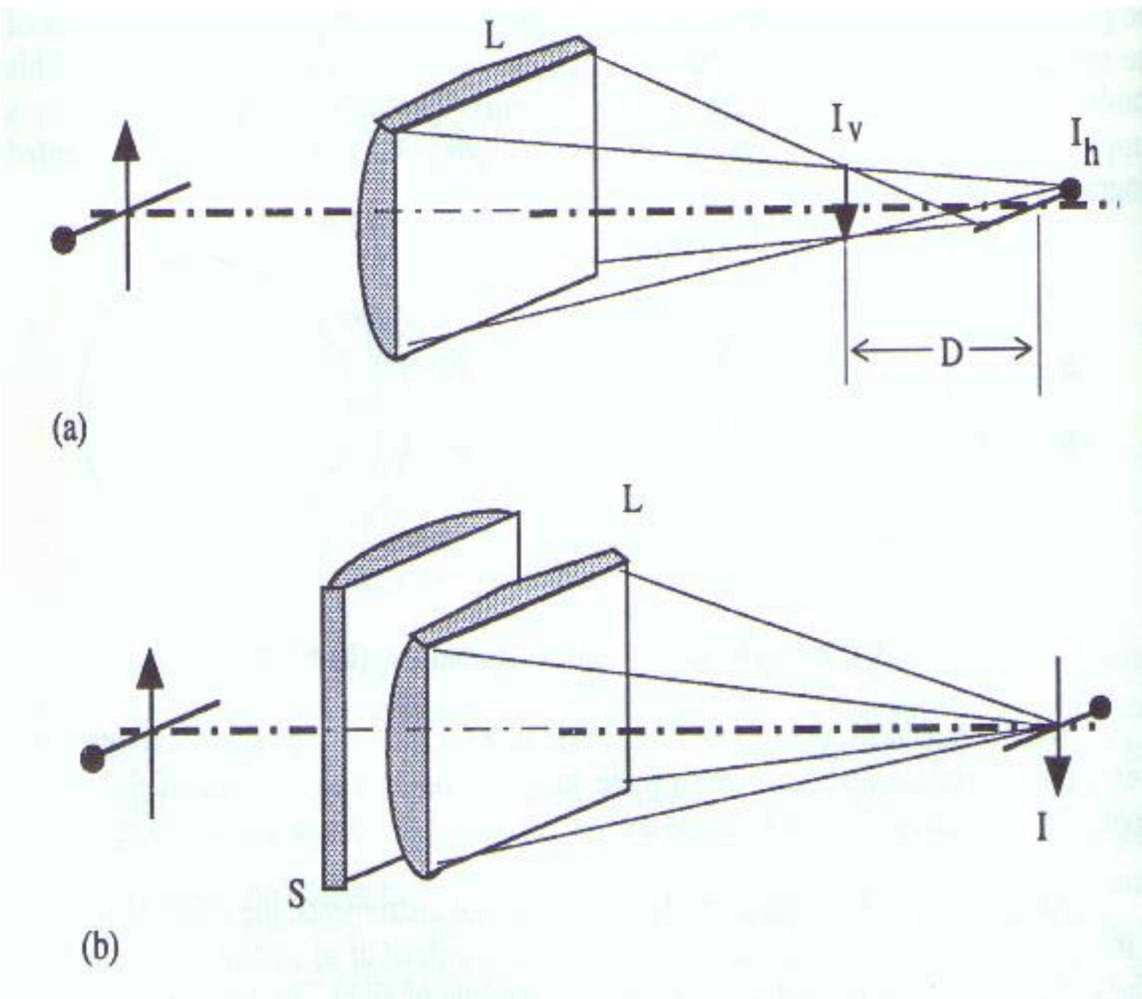


Figure 5: Astigmatism (a) uncorrected (b) corrected. (a) Horizontal and vertical line do not focus at same distance from astigmatic lens. (b) Corrected lens brings entire image into focus at same distance from lens.

Since the curvature in the vertical plane is greater than in the horizontal plane, vertical lines in the object will be imaged at I_v closer to the lens than the images of horizontal lines that are focused at I_h. The astigmatic difference is D. The correction is obtained with a cylindrical lens S with no curvature in one plane and sufficient curvature in the other to make up for the deficiency in the curvature of L. The resulting combination is equivalent to a single spherical lens. If a negative spectacle lens were used having its curvature in the vertical plane, the corrected image would be at I_h.

An astigmatic eye looking at a design such as Fig. 6 will see one set of parallel lines more distinctly than any other set. If you wear glasses for the correction of astigmatism, you will find it instructive to examine Fig. 6 both with and without your glasses. You should also observe the effect of rotating the lenses before your eyes. If you have an astigmatic correction (that is, a cylindrical lens component) you will see a distortion that rotates along with the rotation of the lens.

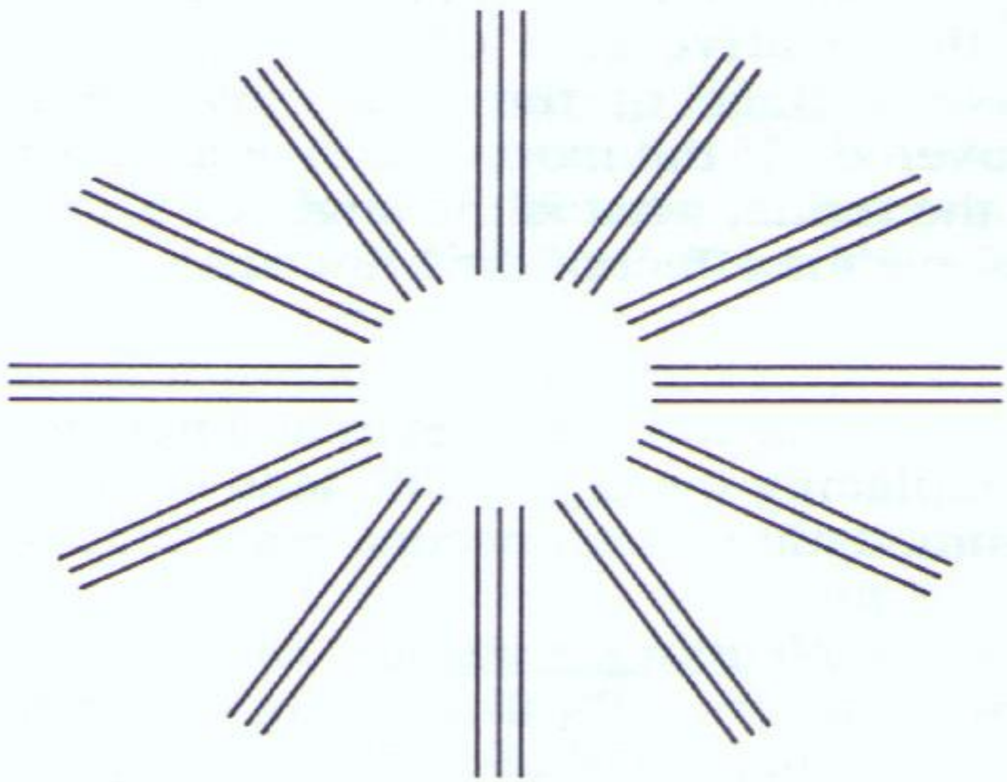


Figure 6. Test Chart for Astigmatism

Spectacle lenses: The lenses used in spectacles may be classified roughly as follows: spherical lenses to compensate for far- and near-sightedness, cylindrical lenses for the correction of astigmatism, and non-spherical lenses designed to correct simultaneously for more than one defect.

The power, or dioptry, of a lens is an index of its ability to bend rays of light; it is measured by the reciprocal of the focal length. The common unit of optical power is the diopter; the power of a lens in diopters being the reciprocal of its focal length in meters. Thus, it follows that one diopter is the power of a lens whose focal length is 1 meter. The power of a combination of lenses used close together is the sum to their individual powers. Thus, a convergent lens of +1.5 diopters and a divergent lens of -2.0 diopter is the equivalent of a single divergent lens of -0.5 diopters (2 meter focal length). It is possible to tell a good deal about the nature of someone's visual defect by an examination of their spectacles. If a distant object is viewed through each lens in turn, the motion of the image resulting from a movement of the lens reveals the type of lens and hence the defect it is designed to correct. If rotation of the lens about the line of sight produces no effect, the lens is spherical. If rotation produces a deformation of the image, the lens is non-spherical and astigmatism is indicated. If a lateral displacement of the lens causes an opposite displacement of the image, the lens is positive; if the lens and the image move in the same direction, the lens is negative. A further check on this may be made by comparing the effects of vertical and horizontal displacement of the lens. If the two displacements of the lens produce unequal displacements of the image, the lens has some curvature in both planes, indicating a compound correction for astigmatism. (As described, this test only checks for the case where the cylinder axis is horizontal or vertical.)

Procedure:

Step 1: Fill the tank of the eye with water to within about 2 cm of the top. Place the metal retina in the normal (middle) position and insert the +7 lens in the septum. **Record the lenses used and their position on your data sheet.**

Step 2: *Accommodation:*

- 1. Face the eye model toward a window or other large, distant and well illuminated object and **note the characteristics of the image on the retina. Estimate approximately the relative size of the image as compared to the object. Record your estimate.**

- 2. Place the illuminated object box about 35 cm in front of the model (corresponding to the distance of distinct vision for the model eye). The most sensitive area, represented by a circle of 1 cm radius in the center of the retina, should be covered: **What is the corresponding angle of vision?**

- 3. Scan the subject by rotating the eye and **observe the effect of the blind spot on portions of the image.**

- 4. Focus the eye by replacing the crystalline liens with the +20 diopter lens, with the illuminated object box about 35 cm in front of the model. This is representative of the accommodation which occurs in a "normal eye". This **should be described. Record your observation on your data sheet.**

Step 3: *Far-sightedness and Near-sightedness:* Keeping the object distance the same, move the retina to the forward position R_h illustrating hypermetropia (Fig. 2). **Select the proper spectacle lens (+2 or -1.75), mount it in front of the eye, and observe the effect on the image. Record the lenses used and their position on your data sheet.** Replace the retina to the normal position and note the nature of the image. This illustrates what happens when a person with normal vision puts on the spectacles of a near-sighted person.

Step 4: *Pupil Size:* With a normal eye, insert the diaphragm immediately before or behind the cornea and examine the image closely. Note the effects upon the brightness and the sharpness of the image. Explain what you observe. Remove the diaphragm and move the object until the initial image is slightly out of focus. Then insert the diaphragm again. **Comment on your observation now. Record the lenses and the diaphragm used, as well as their position on your data sheet.**

Step 5: *Astigmatism:* Starting with a normal eye, with the retina in the normal position, insert the negative cylindrical lens (-5.5 diopter) in the slot behind the cornea with the lens axis vertical. With the object at the normal viewing distance, observe the character of the image. Place the +1.75 diopter cylindrical spectacle lens in the support in front of the cornea and rotate it until the image is most sharply defined. **Note the direction of the axis of the spectacle lens. Record the lenses used, and their position on your data sheet.**

Repeat with the rear lens set at a different angle.

Step 6: *Compound Defects:* With the -5.5 diopter cylindrical lens still in place, combine the effect of astigmatism with myopia by making suitable adjustment of the retina. Make the correction by using the proper combination of spectacle lenses. **Describe the shape of a single lens that would make the same correction.**

Step 7: *Removal of Crystalline Lens:* The crystalline lens is only one part of the lens system of the eye. Sometimes (for instance, in the case of a cataract) the lens has to be removed. Starting with a normal eye, take out the crystalline lens and show, by using the +7 diopter lens as a spectacle lens in front of the eye, that clear vision is still possible. **Note that the image is distinct only for very near objects. Estimate the maximum distance of distinct vision. Record the lenses used and their position on your data sheet.** In recent years, many people with cataracts have their lens replaced with a plastic lens so that they can focus at some distance without an external lens.

Step 8: *The Use of a Magnifier, of Reading Glasses:*

1. With the retina in the normal position, insert the +20 diopter lens as the crystalline lens. This should correspond to the distance of distinct vision of about 35 cm. **Determine approximately the diameter of the image with the object box at the normal distance.**

2. Place the +7 diopter lens in front of the eye to serve as a magnifier and adjust the viewing distance until the image is again in sharp focus. **Record the lenses used and their position on your data sheet. Determine the diameter of the image for this condition. Find the ratio of the image size with the magnifier to the image size without it.**

Finale: When you have finished the experiment, remove all lenses from the eye model, dry them, and replace them in their proper container. Pour the water out of the model.

TABLE 1

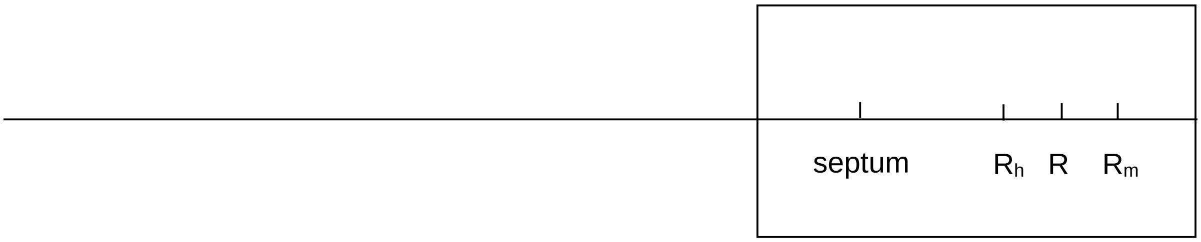
List of lenses for this experiment.

Power in Diopters	Description
+7.00	spherical converging
+20.00	spherical converging
+2.00	spherical converging
-1.75	spherical diverging
-5.50	cylindrical diverging
+1.75	cylindrical converging

Last name: ……………………………… First name: ………………………………

DATA SHEETS

Step 1:



Step 2:

1. Characteristics of the image on the retina (Is the image upright or inverted? Is the image reduced in size or enlarged? Is it real or virtual?)

Relative size of the image as compared to the object:

2. Angle of vision:

3. Effect of the blind spot on portions of the image:

4.

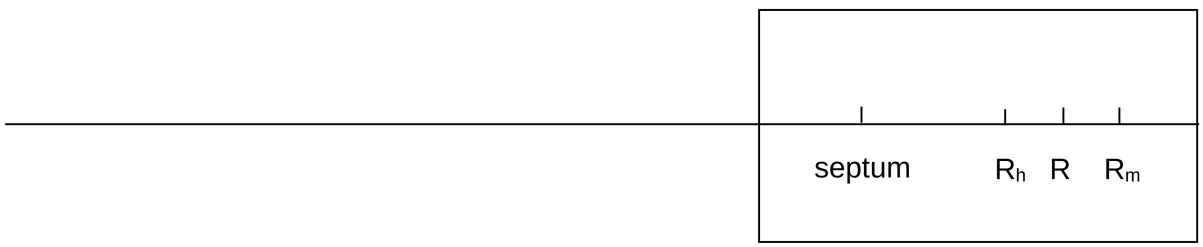
Image characteristics:

Last name: ……………………………… First name: ………………………………

Step 3:

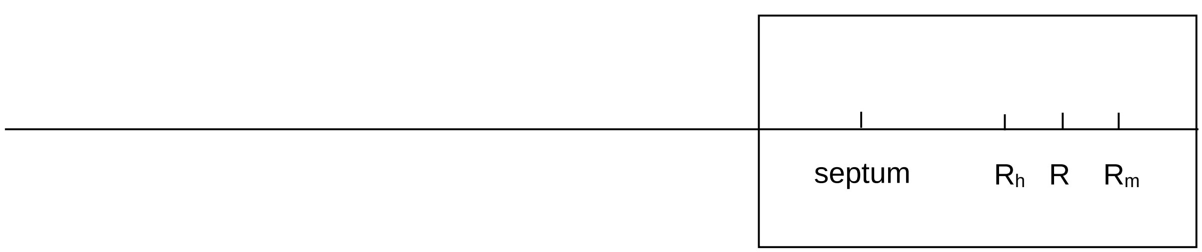
Spectacle lens you used:

Effect on the image:



Step 4:

Observation for the initial image slightly out of focus with the diaphragm inserted:



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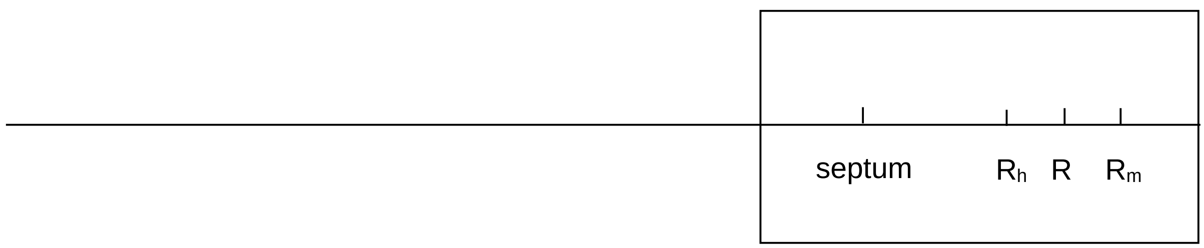
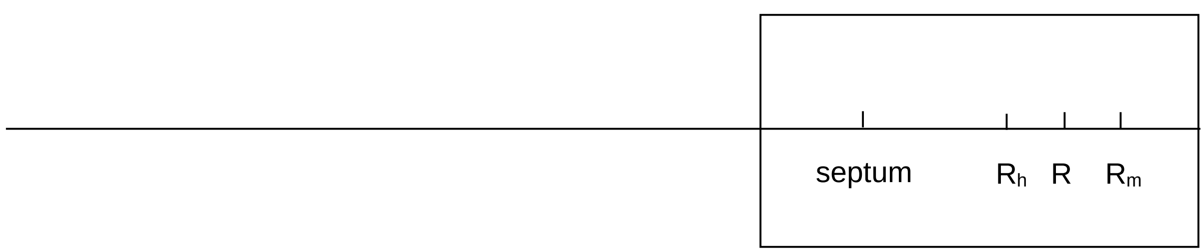
Step 5:

Direction of the axis of the spectacle lens:



Step 6:



Shape of a single lens that would make the same correction:

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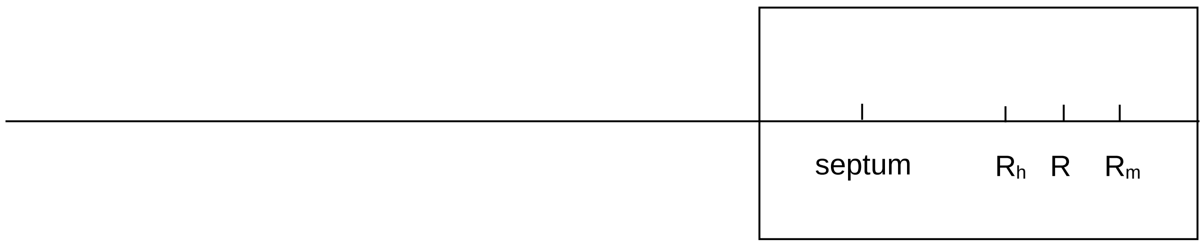
Step 7:

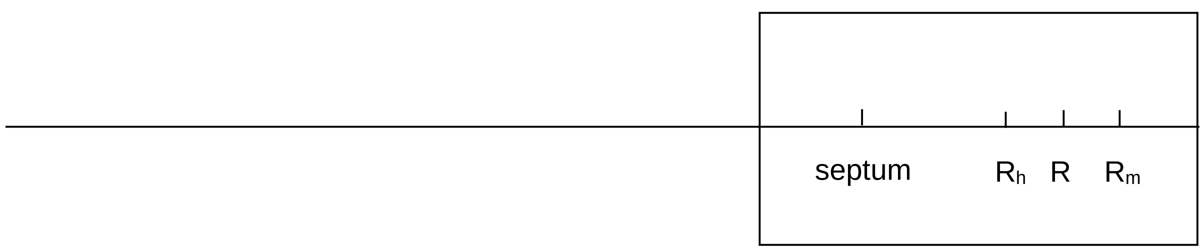
Maximum distance of distinct vision:



Step 8:

1. Diameter of the image with the object box at the normal distance:

2.



Diameter of the image with the +7 diopter lens in front of the eye:

Ratio of the image size with the magnifier to the image size without it: