Learning Optics using Vision

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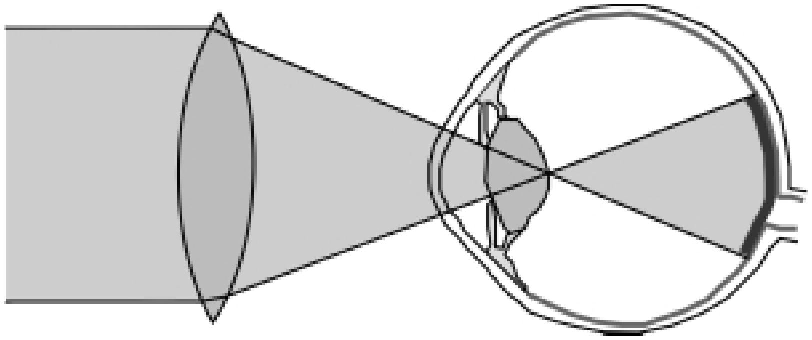


INTRODUCTION

Of the five senses, humans heavily depend on sight. Not until it is taken away from us, even temporarily, do we truly appreciate the amazing biological system of the eye. Our visual system allows us to walk down a path in the middle of the night, determine which snakes are dangerous by its markings, and gauge the distance between you and a wild bear. We are able to differentiate between colors, textures, sizes, and shapes. There are three major components to the visual system: (1) the optics of the eye that focus an image of the environment on the light-sensitive retina, (2) the system of millions of nerves that carry the image to the brain, and (3) the *visual cortex* — the part of the brain that processes the neural signals.

Not only do we depend on our own eyes to see but doctors also depend on our eyes to detect any medical abnormalities. The optic nerve, located behind the retina, carries all the visual information to the brain for processing. It is the only part of the central nervous system that can directly be seen. Ophthalmologists and optometrists make a whole career out of detecting and correcting vision defects. In order for these doctors to use the tools necessary for their job, they need to understand the optics of both the eye, and the instruments they use. The purpose of this handout is to provide a biological context to teach introductory principles of optics.

ANATOMY OF THE EYE

Since the times of ancient Greece, people have tried to uncover the mystery of vision. Ancient Grecians believed that sight entailed tentacles or threads emitted from the eye and physically touched the objects they saw. Through centuries of discoveries and the advancement of technology we have progressed towards a deep understanding about vision. However in centuries to come we will probably understand things about vision that we do not even questioned today.

There are several similarities between the human eye and a photographic camera (Figure 1). A camera is a light-sealed box with a lens system for forming images onto light-sensitive film. A stop and shutter are used to control the amount of light that enters the box. The eye is also a light-sealed box with a two-lens system consisting of a cornea and crystalline lens. The lens system of the eye forms inverted images onto a light-sensitive film, the retina. Lastly, the pupil of the eye controls the amount of light that enters. Our optical system, however have some special features that not even the most expensive cameras have:

1) Eye can observe events over a large angle while concentrating on an object directly ahead of it.
2) Blinking provides a built-in lens cleaner and lubricator.
3) The eye has a rapid auto-focus system called accommodation. It can quickly focus from an object only 20 cm away to one far away in the distance. A relaxed eye is focused for an object at *infinity* (distant viewing).

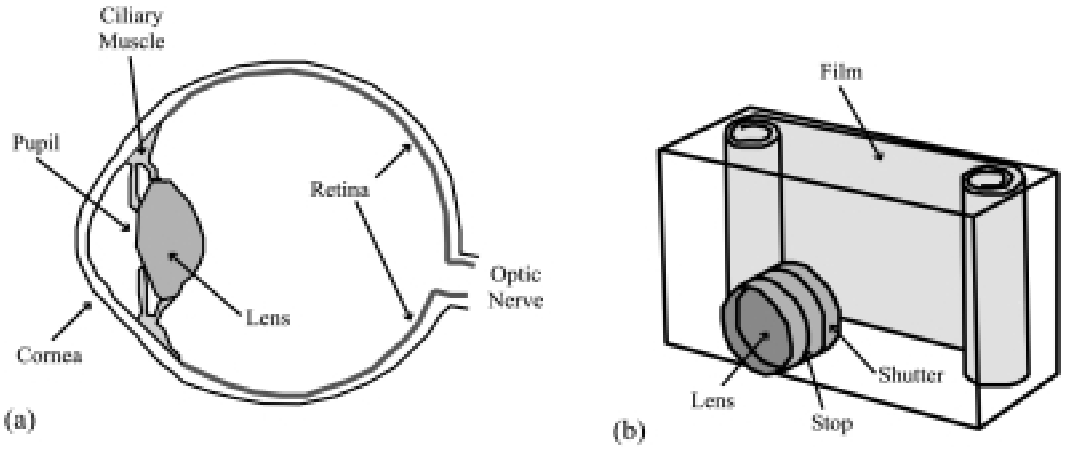


Figure 1 The eye is optically similar to a camera. (a) Human eye. (b) Camera

4) The eye can adapt to light ranges of almost a billion to one (10^{10}:1), bright daylight to very dark night.
5) The eye has an automatic aperture adjustment (the iris) to control the pupil size.
6) The cornea had a built-in scratch remover. The cornea is made of living cells that can repair local damage.
7) The image appears *inverted* or upside down, on the retina, but the visual cortex automatically corrects for this.
8) The visual cortex blends the images from both eyes, giving us good depth perception and three-dimensional viewing. Even if vision is lost in one eye, the vision from the healthy eye is sufficient for normal day-to-day function.

FOCUSING BY THE EYE

There are two main focusing elements of the eye: the *cornea* that is responsible for two-thirds of the focusing, and the crystalline *lens*, which does the fine focusing. To understand how an image is formed on the retina we need to examine the optical properties of lenses and image formation.

Refraction

Light travels through air at a velocity of approximately $3.0 \times 10^8\ m/s$. When traveling through mediums such as transparent solids (i.e. glass) or liquids, light travels at a slower speed. The ratio of the velocity of light in air to the velocity in a medium is known as the **refractive index** and is usually denoted by an *n*. The refractive index for air is 1.00.

Example

Determine the refractive index for a type of glass that slows the velocity of light to $2.0 \times 10^8\ m/s$.

Solution By calculating the ratio of the velocity of light traveling through air to the velocity of light traveling through the glass we find that

$$n_g = \frac{3.0\times10^8\ m/s}{2.0\times10^8\ m/s}$$
$$n_g = 1.50$$

The index of refraction for the glass is 1.50.

When light travels from one medium to a medium with a different refractive index, it will deviate from its original linear path. The bending of light caused by a refractive index mismatch is called **refraction**. The relationship between two mediums and the angle of refraction, as illustrated in Figure 2 is known as **Snell s Law** and looks like this:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

The cornea refracts incident light rays to a focus on the retina. The refractive index of the cornea and other optical parts of the eye are listed in (Table 1). The refractive index of the cornea is near that of water (n= 1.33). This is why when you open your eyes underwater things are not as focused as above water. The index mismatch between water and the cornea is not large enough to refract the light rays to a focus on the retina. If you wore goggles, your vision under water would be normal because you restored the air to cornea interface. As you can see, the indexes of refraction for the interior components of the eye are similar to each other. Once the light enters the eye, very little refraction occurs.

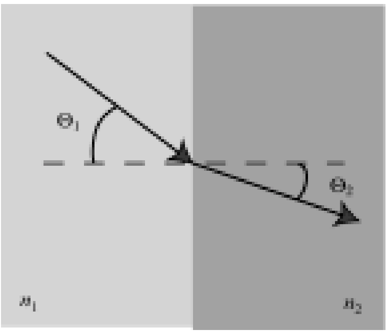


Figure 2 Illustration of Snell's law where $n_1 < n_2$.

Table 1 Indexes of refraction of optical parts of the eye.

Part of the Eye	Index of Refraction
Cornea	1.34
Aqueous humor	1.33
Lens cover	1.38
Lens center	1.41
Vitreous humor	1.34

Lenses

Lenses are usually made of glass or plastic and are used to refract light rays in a desired direction. When parallel light passes through a **convex** lens the beams **converge**, or come together, at a single point as shown in (Figure 3a). On the other hand (Figure 3b) shows that when parallel light passes through a **concave** lens, the beams **diverge**, or spread apart.

The distance beyond the convex lens, where the parallel light rays converge is called the **focal length** of the lens. The relationship between the focal length of a lens, the object position, and the location where a sharp or focused image of the object will appear is

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

This relationship is called the **lens maker s equation**, or thin-lens equation, where f is the focal length of the lens, o is the distance of the object to the left of the lens, and i is the distance of the focused image to the right of the lens. Shown in Figure 3c, a convex lens produces a real, inverted image to the right of the lens. Because a concave lens diverges the incoming light rays, a virtual, upright image is produced to the right side of the lens as can be seen in Figure 3d. Because the cornea is convex shaped, the image formed on the retina is inverted. It is the responsibility of the visual cortex in the brain to invert the image back to normal.

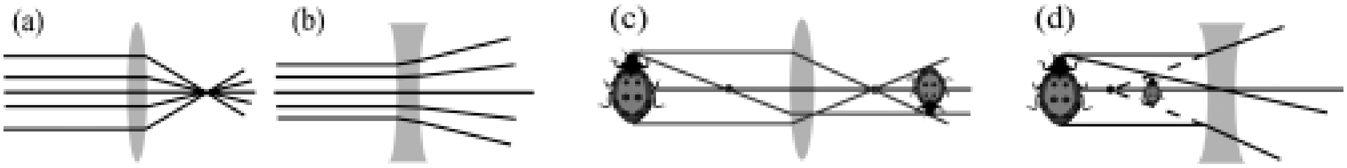


Figure 3 Refraction by a (a) convex lens and (b) concave lens. Inverted image formed by a (c) convex lens and an upright image formed by a (d) concave lens.

The magnification of an image is calculated from following equation:

$$m = -\frac{i}{o}$$

A common sign convention and one we will use in this handout is if an image is formed to the left of a lens then its distance, *i*, is negative and conversely an object that is located to the right of a lens has a negative distance, *o*, from the lens. By using this convention, a positive magnification will represent an upright image and a negative magnification will represent an inverted image.

Cardinal Points

Cardinal points are often used to characterize a thick lens or an optical system. There are six cardinal points (F_1, F_2, H_1, H_2, N_1, N_2) on the axis of a thick lens from which its imaging properties can be deduced. They consist of the front and back focal points (F_1 and F_2), front and back principle points (H_1 and H_2), and the front and back nodal points (N_1 and N_2).

A ray incident on a lens from the **front focal point** F_1, will exit the lens parallel to the axis, and an incident ray parallel to the axis refracted by the lens will converge onto the **back focal point** F_2 (Figure 5a and 5b). The extension of the incident and emerging rays in each case intersect, by definition, the *principal planes*. The principal planes cross the axis at the **principal points**, H_1 and H_2 (Figure 5a and 5b). For a single thin lens, the front and back principal points are located at the center of the lens. The focal length, *f* of a lens is defined by the distance between a focal point and its corresponding principal point. Any ray directed towards the **front nodal point** N_1 of an optical system will emerge from the system at the same angle but is displaced so that it appears to come from the **back nodal point** N_2 (Figure 5c).

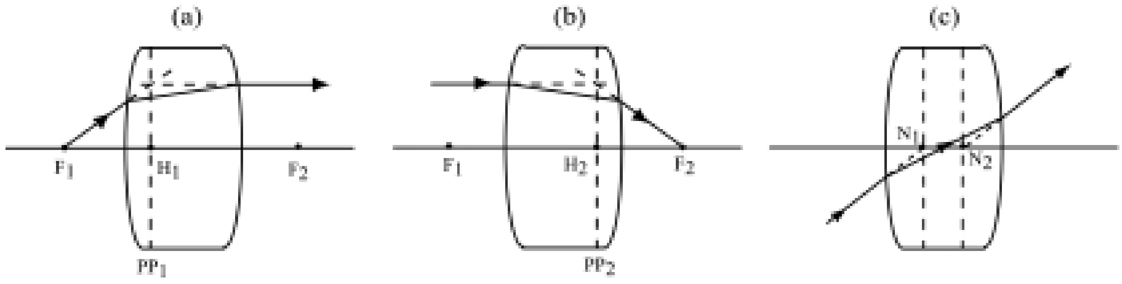


Figure 5 Illustration showing the cardinal points.

Optical Power

The optical power of a lens is commonly measured in terms of diopters (D). A **diopter** is actually a measure of curvature and is equivalent to the inverse of the focal length of a lens, measured in meters. The advantage for using optics power when referring to lens systems is that they are additive. The thin lens equation, in terms of diopters, now looks like

$$P = O + I$$

P is the focal length measured in diopters and O and I are the object and image distances, respectively, measured in inverse meters or diopters. Using units of *diopter* eliminates Opticians need for a calculator to prescribe corrective lens powers.

Example

Calculate the refractive power of a lens that focuses an object 50cm away onto a screen 10cm away.

Solution Using the thin lens equation for optical power we find that

$$P = {}^{1}\!/_{50cm} + {}^{1}\!/_{10cm}$$
$$P = 12D$$

The power of the lens is 12 D.

Accommodation

As mentioned above, the lens of the human eye is responsible for fine focusing. The crystalline lens is not like a typical glass convex lens. It is layered like an onion, where each layer has a different refractive index. The lens is responsible for adapting between near and far point vision. From the lens maker s equation, could see that the lens of the eye would need to have a wide range of focal lengths to focus objects that are close to the eye versus far away. Instead of having hundreds of different lenses, *ciliary muscle* (Figure 1) attached to the crystalline lens contract and relaxes, causing a change in the lens curvature, thus changing its focal length. The ability to change focal lengths to focus objects at different distances is called **accommodation**. For distant objects the ciliary muscle relaxes and the lens forms a flatter configuration, increasing its radii of curvature and therefore decreasing the power. As the objects moves closer, the ciliary muscle contracts, making the lens fatter and producing a higher power lens. A normal young adult is capable of increasing the refractive power of their eye from 20 D to 34 D. Unfortunately, as a person ages, their lens begins to harden and their ability to accommodate deteriorates. This condition is called *presbyopic* and is discussed later in this handout.

Diffraction Effects on the Eye

When light travels through a small aperture the rays that pass by the edge of the aperture will not travel in a straight line. The scattering of these rays will produce a blurry image. This dispersion of light caused by it passing through an aperture is called **diffraction**.

The pupil of the eye is a circular aperture therefore; when light travels through the pupil it produces a diffraction pattern on the retina that looks like Figure 6. The width of the center maximum is inversely dependent on the radius of the aperture. Therefore, the diffraction effects under normal conditions where the pupil opening is about 4 mm will not noticeably degrade our vision. However, when light conditions are brighter, the pupil will instinctively decrease in size, increasing blur on the retina due to diffraction effects.

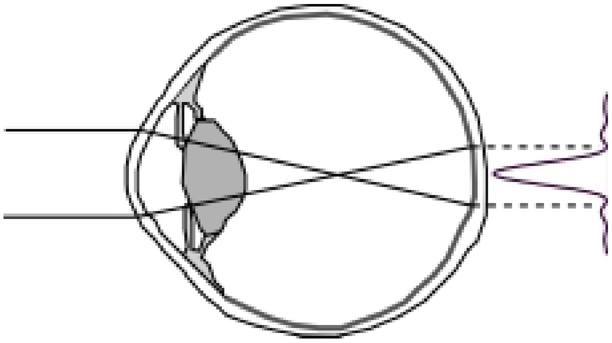


Figure 6 Diffraction pattern on the retina produced by the pupil. The diffraction pattern broadens as the pupil size decreases. In bright light, the image on the retina is blurry due to diffraction.

OPTICAL MODELS OF THE EYE

A normal biological eye is close to a sphere in shape with a diameter from the cornea to the retina of about 23 mm. Over the years several attempts have been made to adequately model the human eye. In this section we will discuss two popular models. These models are

1. Gullstrand s three-surface, simplified schematic eye
2. Emsley standard reduced 60-diopter eye

Gullstrand s Three-Surface Simplified Schematic Eye

In 1911, A. Gullstrand received the Nobel Prize for Physiology for his investigations on the dioptrics of the eye. Based on his work Gullstrand designed a simplified model for the human eye shown in Figure 7. The lens is considered to have an average index of refraction of 1.413, and the axial distance from the cornea to retina is 24.17 mm. These two parameters ensure that parallel rays entering they will focus perfectly on the retina. Gullstrand s three-surface model allows for changes in the power of the lens by adjusting the curvatures of the front and back surfaces. This attribute is very useful for calculating image positions when the natural lens is removed, during cataract surgery, and replaced by an artificial fixed lens.

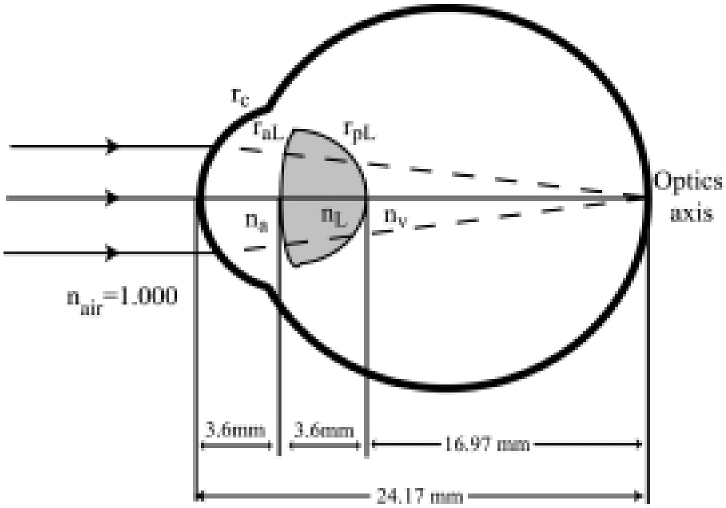


Figure 7 Gullstrand s three-surface simplified schematic eye

Emsley Standard Reduced 60-Diopter Eye

The Emsley standard reduced 60-diopter eye is one of the simplest models of the eye and most often used in ophthalmic education (Figure 8). It contains a single refracting surface and only one index of refraction mismatch between the air and the vitreous humor. The axial distance from the cornea to the retina is 22.22 mm. Unlike the three-surface simplified schematic model, accommodation calculations cannot be done. The two principal points and two nodal points are combined into single principal and nodal points (H and N). The corneal surface of 60 D power encompasses the separate refractions of the corneal and lens interfaces, representing the total focusing power for the eye.

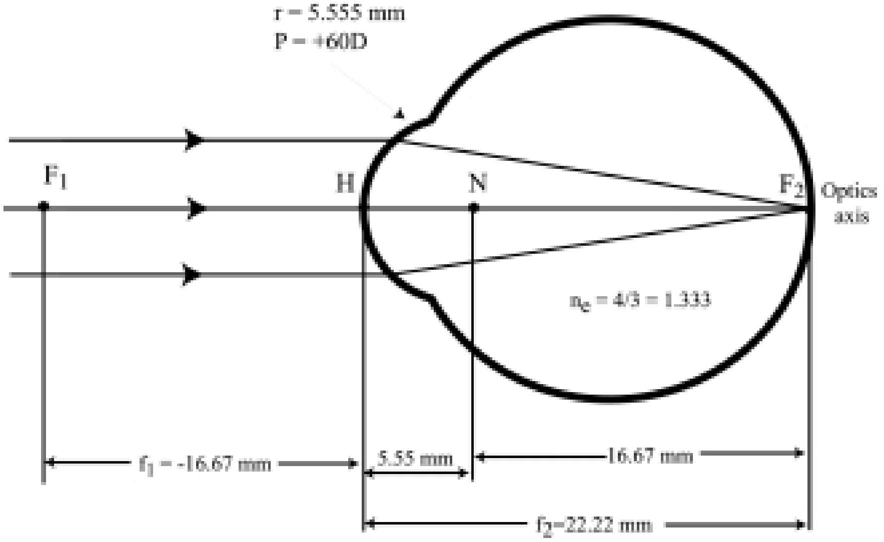


Figure 8 Emsley s standard reduced 60-diopter eye.

DEFECTIVE VISION AND ITS CORRECTION

When you go to the optometrist to get your eyes check you probably looked at a Snellen chart similar to the one shown in Figure 9. These charts test the visual acuity of your eyes and help the doctor determine whether you need corrective lenses. Simply stated, **visual acuity** is the ability to see clearly or the resolution of the eye. If your eyes test normal at 20/20, it means that you can read letters from 20 ft that a person with good vision would read 20 ft away. If your eyes test at 20/40, then you can read something from 20 ft away that a person with good vision can read 40 ft away.

A normal, 20/20 eye is called **emmetropic** when rays from a distant object and a near object can come to a focus on the retina. An eye unable to do either or both of these tasks is called *ametropic*. There are three common defects in vision: myopia, hyperopia, and presbyopia. Each of these conditions and how they are commonly corrected are explained in detail below.

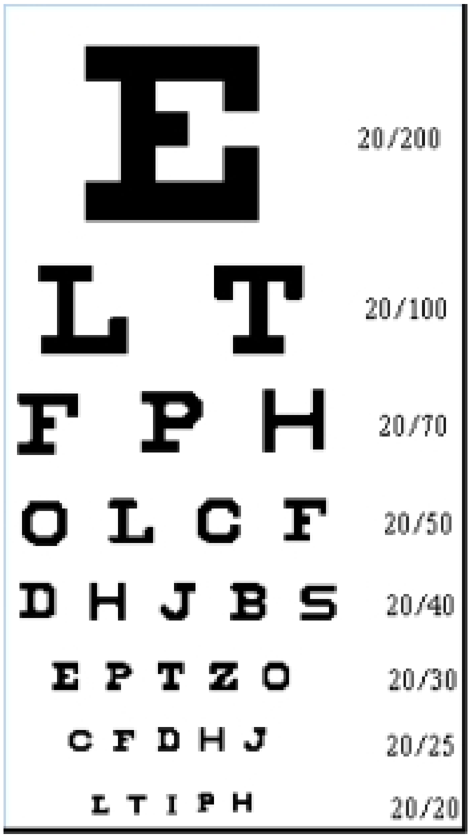


Figure 9 Snellen eye chart. Charts like these are commonly used to test a person s visual acuity.

Myopia

Myopia, or near-sightedness, is a very common condition among young adults. A myopic person is unable to clearly see a distant object yet is able to focus near objects (Figure 10). A myopic eye has too large refracting power for a longer-than-normal eye. Light rays from a distant object focus in front of the retina producing a blurry image on the retina. The myopic far point (MFP) is the farthest distance an object is located from the eye that still produces a focused image on the retina. A fully accommodated myopic eye can focus objects closer to the eye than normal. This distance is called the myopic near point (MNP).

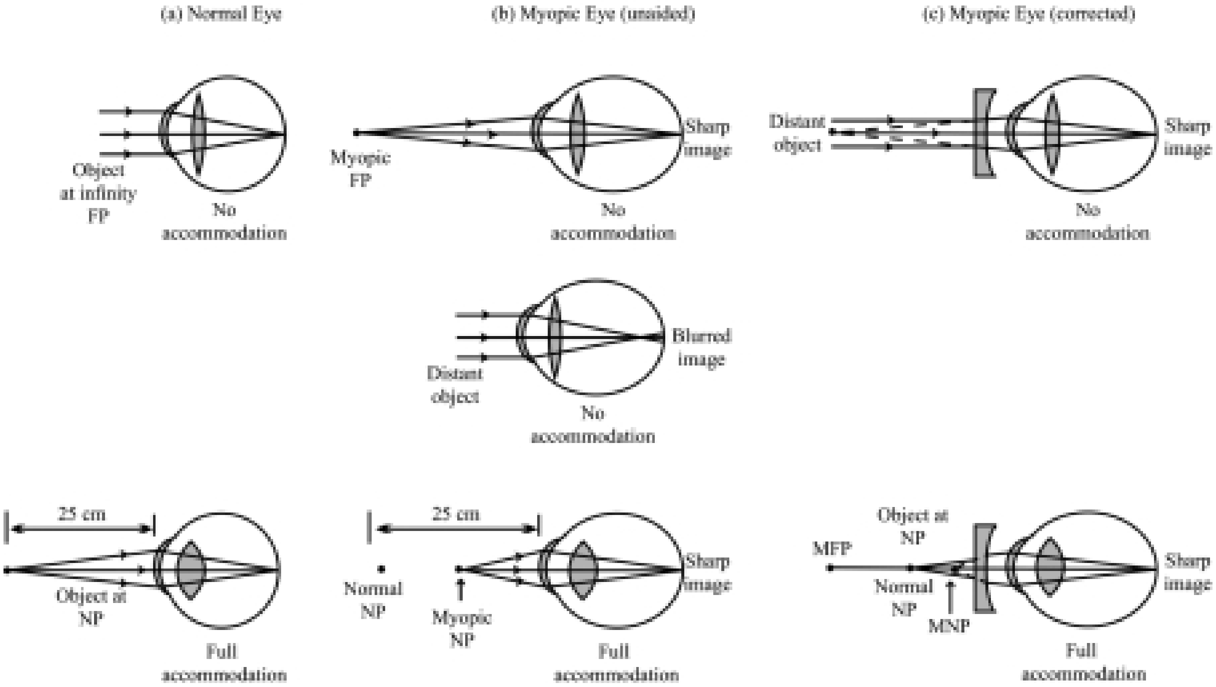


Figure 10 A comparison of (a) normal and (b) myopic vision (c) with correction.

Hyperopia,

Hyperopia is more commonly known as far-sightedness. A hyperopic person is unable to clearly see near-by objects. Opposite of the myopic eye, the hyperopic eye has too little converging power for the shorter-than-normal eye. As illustrated in Figure 11a, a hyperopic eye never focuses the light coming from a near-by object before it hits the retina. Thus, a sharp image is never formed on the retina. The focal point behind the retina is considered the **hyperopic far point** (HFP). A partially accommodated hyperopic eye can still focus objects far away. When the eye is fully accommodated, the nearest distance of an object from the eye that will produce a focused image on the retina is called the **hyperopic near point** (HNP).

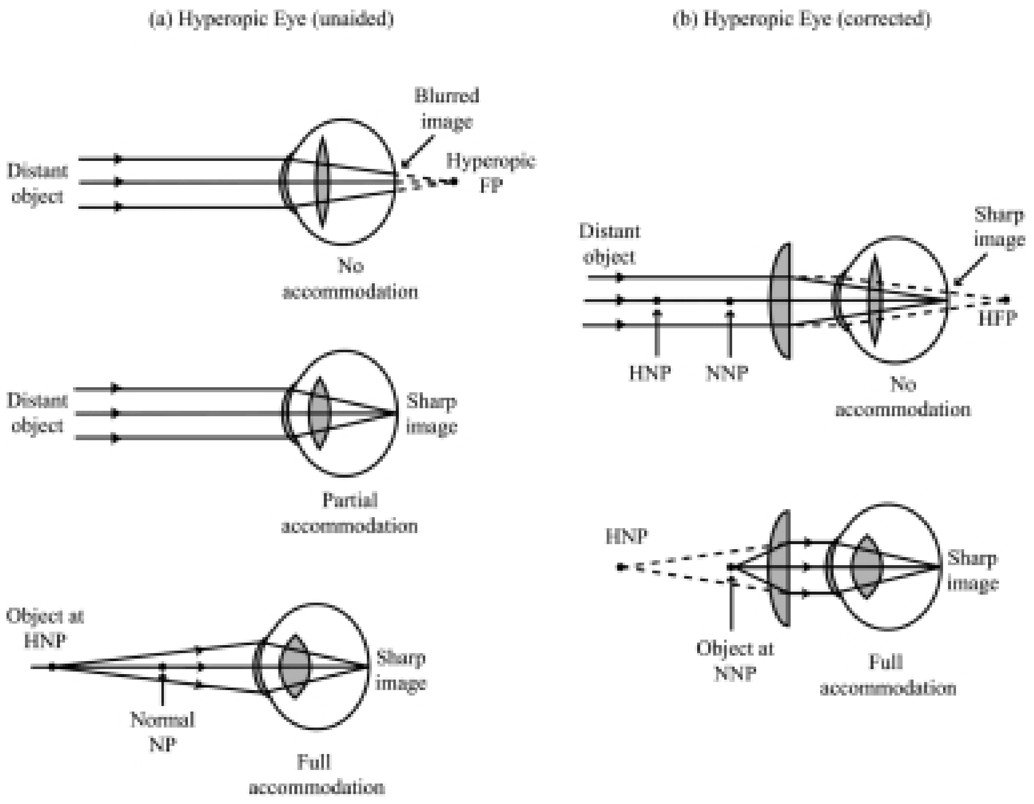


Figure 11 Hyperopic vision with correction.

Presbyopia

Presbyopia is a condition where the eye loses its ability to accommodate with age. Recall, the ciliary muscle contracts and squeezes the lens so that it has a shorter focal length to accommodate for near point objects. Over time, the crystalline lens gradually hardens, decreasing the flexibility of the lens, making it more difficult to focus near-by objects. Loss of accommodation begins at a very early age; however not until the age of about 40 years will a person begin noticing they have trouble reading fine print and need to hold a book farther away to focus clearly.

Vision Correction

Myopia, hyperopia, and presbyopia are routinely corrected with spectacles. Too much convergence (positive power) causes myopia, a negative power, or diverging lens is used to refocus rays from far distances onto the retina (Figure 10c). The negative lens will move the myopic far and near points outward to normal positions. Conversely a hyperopic eye requires a positive power lens to move the hyperopic near and far points inward (Figure 11b). As one may suspect from its name, lens maker s equation is used to calculate the lens power needed to correct either condition. Presbyopic correction is similar to hyperopia in that a positive lens will compensate for the eye s inability to accommodate. Presbyopes usually wear reading spectacles for near point activities, such as reading. A presbyopic person who already wears spectacles to correct myopia or hyperopia will usually switch to bifocals.

An increasingly popular method for vision correction is the use of contact lenses. Contact lenses are based on the same principles as spectacles in that a negative lens corrects myopia and a positive lens corrects hyperopia. If you have ever switched from spectacles to contact lenses you may have noticed a power change in your prescription, even though your vision was the same. This is because the contact lens is located on the cornea and spectacles are several millimeters in front of the eye. Between the two positions, the vergence (either convergence or divergence depending on lens type) of the lens is changing. When using spectacles, the power of the lens needs to focus the light (in combination with the corneal lens) a distance x longer than contact lenses (Figure 12). In general, the power of a lens needed to compensate of a distance shift is called the **effective** power. For the case of lens correction we use the following equation:

$$P_c = \frac{P_s}{1 - xP_s}$$

to calculate the contact lens power required to switch from spectacles with power P_s located a distance x from the eye. To calculate the spectacle power from a contact lens power the P_s and P_c terms are simply switched.

Example

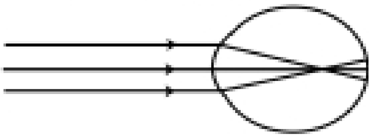
Suppose that a myope uses spectacle lenses of —10 D and wishes to change to contact lenses. His cornea is at a distance of 13 mm from the spectacles. What should be the contact lens power to provide equivalent correction?

Solution Now, x = 13 mm, and P = -10 D. Then

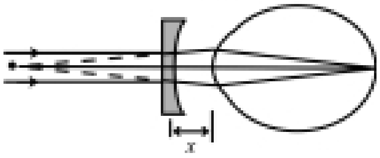
$$P_c = \frac{P_s}{1 - xP_s} = \frac{-10}{1-(.013)(-10)} = -8.85D$$

The contact lens must be of lesser negative power than the spectacle lens due to the decrease in vergence of the light.

(a) Unaided Myopic Eye



(b) With Spectacle Lens



(c) With Contact Lens

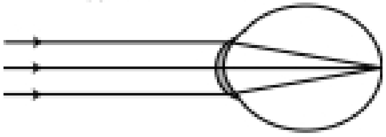


Figure 12 Equivalent correction of (a) a myopic eye by using either (b) a spectacle lens a distance *x* from the cornea or (c) a contact lens at the cornea. Prescription power differs between the spectacle lens and contact lens.

ABERRATIONS OF THE EYE

By assuming that all the rays that hit lenses is paraxial, we have ignored the dispersive effect caused by lenses. Saying that spherical lenses and mirrors produce perfect images is not entirely correct. Even when ground and polished perfectly, lenses do not produce perfect images. The deviations of rays from what is ideally expected are called **aberrations**. There are five main types of aberrations: *spherical, astigmatism, coma, field curvature,* and *distortion*.

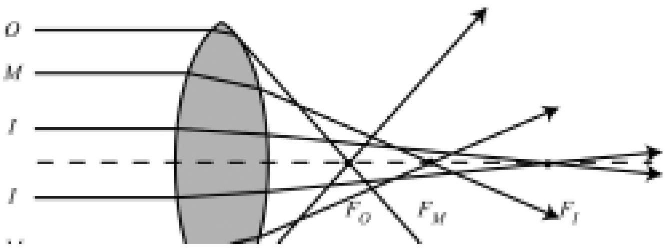


Figure 13 Spherical aberration in a converging lens. The paraxial rays, I, have the farthest focal point, F_I. The outer rays, O, bend the most and therefore have the closest focal point, F_O. The middle rays, M, focus between the two extremes.

Spherical Aberrations

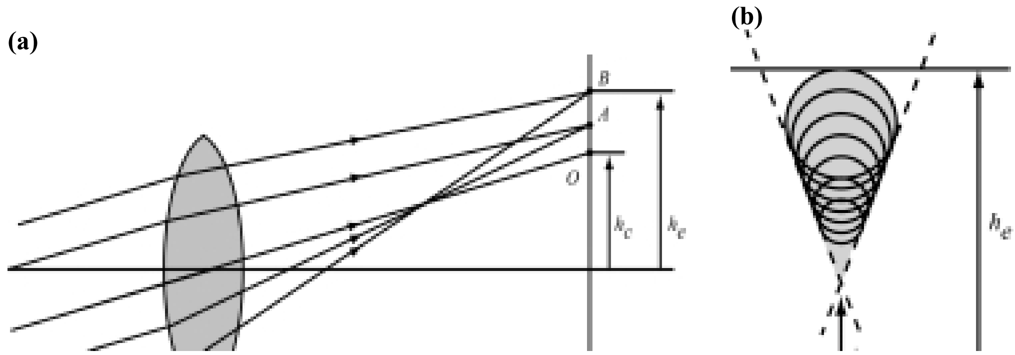
When paraxial rays pass through the edges of a spherical lens they do not pass through the same focus (Figure 13). A blurred image formed due to the deviations of the rays passing through the edges of the lens is called spherical aberration. As you may imagine, spherical aberrations are a greater problem is optical systems with large apertures. Under normal conditions, the human pupil is small enough that spherical aberrations do not significantly affect vision. Under low-light conditions or when the pupil is dilated, however, spherical aberrations become important. The visual acuity becomes affected when the pupil is larger than about 2.5 mm in diameter. So, as you may recall, if the pupil size become too small, the visual acuity decreases due to diffraction. Yet, when the pupil size becomes too big, spherical aberrations will too decrease visual acuity.

There are other factors of the eye that reduces the effect of spherical aberrations. The outer portions of the cornea have a flatter shape and therefore refract less than the central areas. The central part of the crystalline lens also refracts more than its outer portions due to a slightly higher refractive index at its center.

Spherical aberrations can be correcting using aspheric spectacle lenses. Aspheric lenses have surfaces that are not exactly spherical. The aspheric lens is designed to correct for excessive refraction that may occur around the edges of the cornea.

Coma

Coma is an off-axis modification of spherical aberration. Coma produces a blurred image, shaped like a comet, of off axis objects (figure 14). Like spherical aberration, coma is a pupil size dependent aberration of the eye. It can also be corrected using an aspheric lens. An optical system free of both coma and spherical aberration is called *aplantic*.



Astigmatism

Astigmatism is a difference in focal length for rays coming in different planes from an off-axis object. Like coma, astigmatism is nonsymmetric about the optical axis. The eye defect called astigmatism is slightly different than the optical aberration. The eye defect, astigmatism refers to a cornea that is not spherical but is more curved in onw plane than in another. In other words, the focal length of the astigmatic eye is different for rays in one plane than for those in its perpendicular plane. Ocular astigmatism is corrected by a lens that converges (or diverges) rays in specific planes, while not affecting rays in the perpendicular plane. These lenses are called cylindrical lenses. The cylindrical component of a patient s spectacle prescription refers to the correction of astigmatism.

Figure 14 Coma (a) due to parallel rays, each image point in the figure becomes the top of a comatic circle of image points. (c) Formation of a comatic image from a series of comatic circles. The angle between the dashed lines is 60°.

Field Curvature

Field curvature causes a plane surface object perpendicular to the optical axis to image as a curved surface (figure 15). This aberration is remedied by using a curved imaging plane. Field curvature is not an important aberration of the eye. The curvature of the retinal surface corrects for curvature in the image.

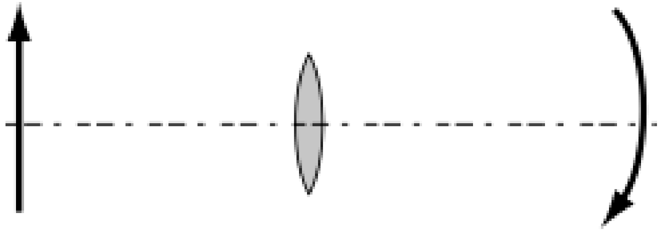


Figure 15 Curvature of field due to a converging lens

Distortion

Distortion is a variation in the lateral magnification for object points at different distances from the optical axis (figure 16). If magnification increases with the object point distance from the optical axis the image of figure 16a will look like figure 16b, called pincushion distortion. Conversely if the magnification decreases with object point distance the image has barrel distortion figure 16c. Both images are still sharp, just distorted. There is little distortion in the eye itself.

DIRECT OPHTHALMOSCOPE

The direct ophthalmoscope is a hand-held, self-illuminating optical instrument that allows a physician to look into a patient s eye. Hermann von Helmholtz invented the ophthalmoscope in 1851 to view the optic disk, retina, blood vessels and other contents found at the back surface of the eye. Figure 17a shows a simplified schematic of the ophthalmoscope. The bright light from the source is reflected off of an angled mirror into the subject s eye. The light diverges toward the lens system of the subject s eye. Assuming both the subject and observer have emmetropic eyes, the rays are parallel to each other because the retina is located one focal length from the lens. Light from the illuminated part of the retina leaves the lens system of the subject s eye in the form of parallel rays towards the observer. Because the rays are parallel, the lens system of the observer s eye treats the image of the subject s retina as a distant object and focuses it to a spot on their retina. Figure 17b shows what one would see if they were looking at a normal retina through the ophthalmoscope.

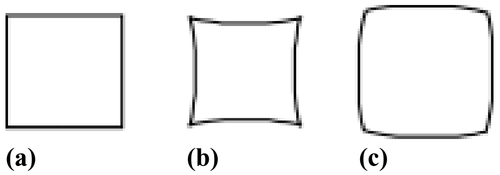


Figure 16 Images of (a) a square, (b) showing pincusion distortion, and (c) barrel distortion, due to nonuniform magnifications.

To correct for hyperopia or myopia of the subject and/or observer a variety of corrective lenses are available within the ophthalmoscope. As noted above, the ophthalmoscope is designed so that the observer s lens system can image the subject s retina as though it is far away from the observer. Normal adult eyes have a tendency to accommodate when two eyes come close together. This accommodation causes an approximate +2 D increase in strength in the lens of the eye. So even for the case of both an emmetropic subject and observer, it is very likely a — 4 D lens is needed to see a clear image of the subject s retina.

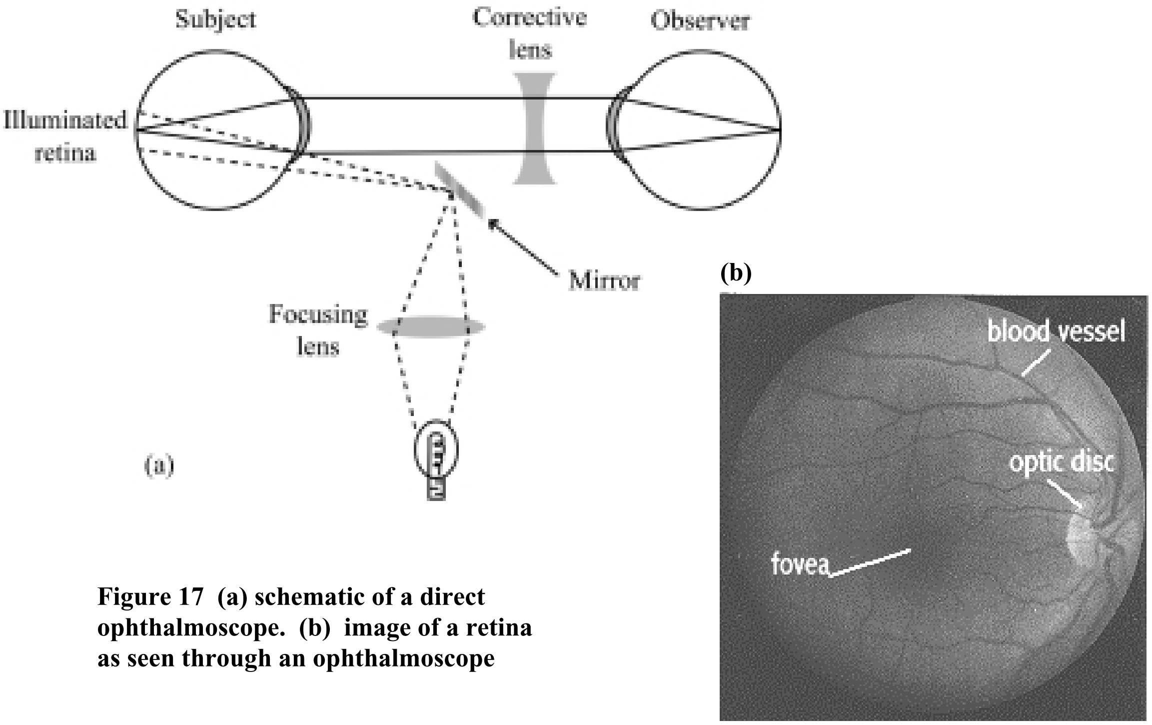


Figure 17 (a) schematic of a direct ophthalmoscope. (b) image of a retina as seen through an ophthalmoscope

References:

- Pedrotti L and Pedrotti F; Optics and Vision. Prentice-Hall, New Jersey 1998.
- Falk D, Brill D, and Stork D; Seeing the Light. John Wiley & Sons, New York 1986.
- Cameron J, Skofronick J, and Grant R; Physics of the Body. Medical Physics Publishing, Madison, Wisconsin 1999.

Sample Problem Set

1. Using Emsley s standard reduced 60*D* eye model, compute the size of an image of a spider, 3*mm* in diameter, on the retina. The spider is on the wall 3.0*m* away.

Solution: From Emsley s model, we know that the image distance i, is $22.22mm$. We also know the cornea is a convex lens and will form a real, inverted image on the retina. We calculate the magnification (or minification for this case) of the image of the spider is

$$m = -\frac{0.022m}{3.0m} = -7.33 \times 10^{-3}$$

And therefore the size of the image of the spider on the retina is $7.33 \times 10^{-3} \times 3mm$ or $22\mu m$. The negative sign indicates that the image is inverted.

2. Determine the strength of a lens needed to correct a myopic eye that has a far point of 2.0*m*.

Solution: To correct myopia we need a lens that will image an object located far away onto the myopic far point. Recall, the myopic far point is the farthest distance from the eye that an object can be so that the eye is still able to focus its image onto the retina. Using the thin-lens equation for optical power

$$P = O + I$$
$$P = \frac{1}{\infty} + \frac{1}{-2.0m} = -0.5D$$

we find that we need a negative lens with -0.5*D* to correct this vision.

3. Determine the strength of a lens needed to allow a hyperopic person that has a near point of 2.0*m* to thread a needle 0.25*m* away.

Solution: To correct hyperopia we need a lens that will image an object that is close to the eye onto the hyperopic near point. Recall that the hyperopic near point is the closest distance an object can be to the eye so that its image is focused onto the retina. Using the thin-lens equation for optical power

$$P = O + I$$

$$P = \frac{1}{0.25m} + \frac{1}{-2.0m} = 3.5D$$

we find that we need a positive lens with $3.5D$ to correct this vision.

4. On examination, an optometrist finds that a patient who was formerly emmetropic now has a near point of $0.5m$ and lies to read at a distance of $0.25m$. What is this condition called and what strength reading glasses should be prescribed?

Solution: We need to image the object onto the near point so the eye can properly focus the intermediate image onto the retina.

$$P = O + I$$

$$P = \frac{1}{0.25m} + \frac{1}{-0.5m} = 2.0D$$

The reading glasses should have strength of $2.0D$.

5. Suppose the prescription power of a contact lens for hyperopia is $+10D$. If the person is to be fitted instead with spectacle lenses, worn at a distance of $14mm$ from the cornea, what is the required prescription?

Solution: Using the equation for effective power

$$P_s = \frac{P_c}{1 - xP_c}$$

$$P_s = \frac{10D}{1-(-0.014m)(10D)} = 8.77D$$

The spectacle lens for the hyperope is $8.77D$. It is lesser power than the contact lens because the spectacle lens is farther from the cornea and therefore requires less convergence.

Lab Experiments

The Optics of the Eye

Blind Spot

All of the nerves of the retina bundle together to form the optic nerve. Where the optic nerve exits the eye there is a blind spot. At this spot there are no photoreceptors, therefore no light can be detected. You can find your own blind spot.

Directions:

On a notecard draw an x and a large dot about 2 inches to the left of the x .

Close the left eye and focus the right eye on the x of the notecard.

Start the card about five inches from your eye and slowly move it away from you, while maintaining focus on the x .

At a certain distance the dot will disappear. If you move the card even further, the spot should reappear.

If you assume the fovea is located in the center of the retina, you can calculate the distance from the fovea to the optic disk by measuring the distance the notecard is from your eye.

Inverted Image

The image formed by the lens of the eye onto your retina is inverted, or upside down. Objects appear upright because your brain will revert the image back to normal. However, if an object is placed within the primary focal distance of the eye, it forms a blurred image on the retina that is also inverted.

Directions:

Position a pinhole about an inch from one eye.

Now hold the tip of a pen between the pinhole and your eye. You should see an inverted image of the pen tip.

By measuring the distance between the pen tip and your eye, you can draw a ray-tracing diagram to show exactly how the image forms on your retina.

You can also see that images are inverted on the retina by doing the following:

While looking at a white sheet of paper, gently press the outside of one eye, you should see a black spot form near your nose.

It is believed that by gently pressing on the eye, blood flow to that area on the retina is restricted, thus you see a dark spot. The spot you see, however, is toward the opposite side of the finger because the image on the retina is inverted. Light from the side near your ear is imaged on the part of your retina near your nose.

The Optics of the Eye II

Using an Ophthalmoscope

As you know, doctors use ophthalmoscopes to view the back of their patient s eye. In your handout a simple diagram of on ophthalmoscope is provided (Figure 8). Here you can learn how to look through an ophthalmoscope and observe your partner s retina.

Directions:

To turn on the power source, press down on the green button and twist the ring.

Bring the flat side of the scope up to you eye, looking through the aperture.

Find the correct corrective lens so that objects are in focus.

While looking through the scope, bring it near your partner s eye, slightly from the side, so that the light is shining into his/her pupil but not from straight on.

Move the scope slightly until you see an image like the one in Figure 9 of your handout.

If the image is not clear, change the power of the corrective lens until it is.

Measuring your Eyeglass Prescription

You can easily measure the prescription of your eyeglasses. Your eyeglass prescription is simply the power (in diopters) of your lenses. If you do not suffer from astigmatism, your eyeglass lenses are spherical lenses and you need only measure the focal length of each lens to determine its power.

There are several ways you can determine the focal length of a lens. Here is one suggestion:

> Using a distant light source, say the ceiling room lights, you can focus the image of the lights onto a screen (white paper) on the floor using a lens.
> Move the lens farther away from the floor until the image of the lights is focused on the screen.
> The focal length of the lens is the distance between the screen and the lens.
> You can then calculate the power of the lens in diopters.

Test for astigmatism.

Here is a simple test for astigmatism:

> Close one eye and view Figure 1 through the other eye (without glasses or contact lenses).
> Hold the figure sufficiently close to the eye so that all lines look blurred.
> Gradually move the figure away until one set of lines comes into focus, with the rest blurred. (If two adjacent sets come into focus together, rotate the figure a little until only one is in focus. If all sets come into focus together, you don t have astigmatism.) You have now found the near point for a line in a direction of the lines that are in focus.
> Move the pattern away further until the lines perpendicular to the first set come into focus. (The first set may or may not remain in focus.) This is the near point for a line perpendicular to the original set.
> The different near points mean that your eye has a different focal length for lines parallel to and perpendicular to the original set.
> Try the procedure again with your glasses or contact lenses to see if your astigmatism is corrected.

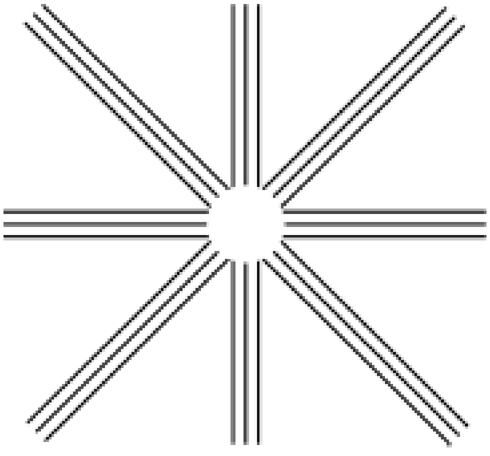


Figure 1. Test for astigmatism

Design an Artificial Eye

You can design an artificial eye using Emsley s standard reduced 60-diopter eye model.

Set up the correct power lens to represent the cornea.

Place a screen behind the lens in place of the retina. Because there is no lens to represent the crystalline lens of a real eye, we expect that the model cannot account for accommodation.

You can measure the near point of the eye by moving an object to the closest distance from the eye that still forms a focused image on the artificial retina (screen). The far point should be infinity.

By changing the power of the cornea, you can build a model for a myopic or hyperopic eye and design corrective lenses:

Determine the near and far point for a few different amounts of myopia.

Do the same for a few different amounts of hyperopia.

For each myopic and hyperopic condition you model, calculate the spectacle lens needed to correct it.

Check your calculations by placing an additional lens in front of the model eye to simulate eyeglasses and measuring the new near and far points. The corrected near and far points should be about the same as for the emmetropic 60-diopter eye.