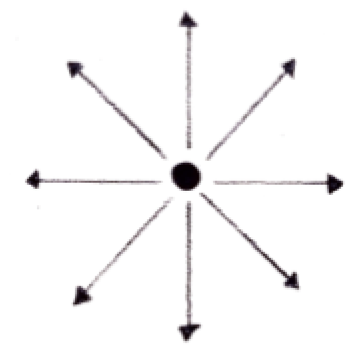
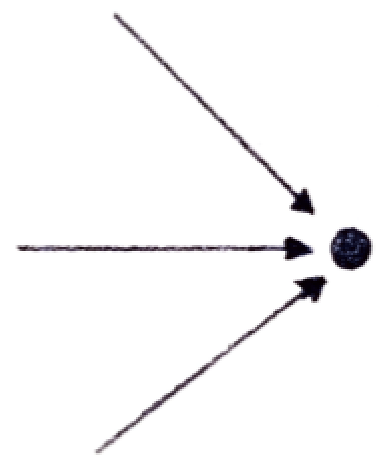
Refractive Error

LIGHT PROPAGATION AND REFRACTION

Light propagates from an object in every direction through the surrounding medium. If the object is a light source (i.e. a computer screen) the light is emitted as it originates from the object. All other objects reflect light from other sources off of their surfaces. Light rays propagate in a linear and radial pattern from a single point until impeded or altered by some other object. The light rays diverge (expand and increase in distance from each other) as they propagate away from the originating object.



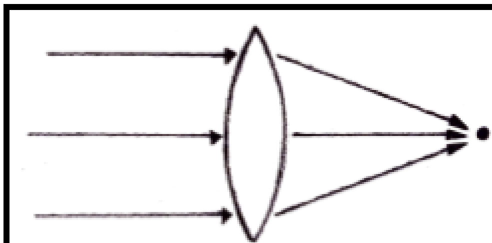
Light propagates in all directions (divergence) from a single point.



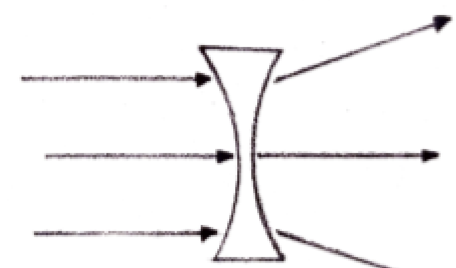
Light converging to a single point to form a clear image.

In order for light from an object to form a clear, viewable image, the light rays from the object need to converge. When light rays converge, they decrease in distance from each other and focus at a point to form an image.

In order for diverging light rays to become converging light rays, they must be redirected by a lens. This phenomenon is called refraction and occurs when rays of light travel into a new medium or lens with a different index of refraction, such as glass, compared to the previous medium, such as air. The amount that light is refracted by a lens is called the power of the lens, and the amount of power is determined by the lens' index of refraction and the radius of curvature of each surface. Lenses can have positive plus (+) power or negative minus (-) power. Positively powered lenses redirect rays to converge more (or diverge less), while negatively powered lenses redirect rays to diverge more (or converge less).



Light rays from an object refracted by a plus lens into converging rays to form a point image.

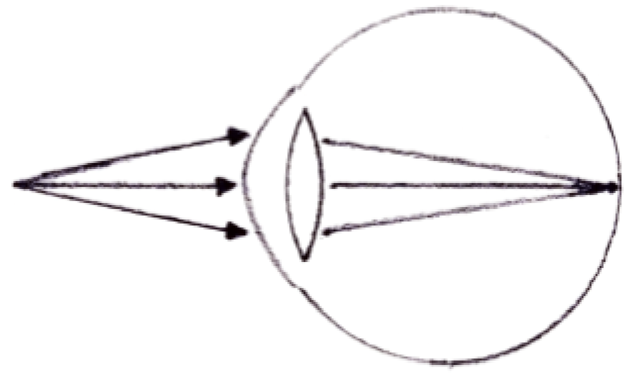


Light rays from an object refracted by a minus lens into diverging rays.

Plus-powered lenses must have at least one convex surface, and they can converge light rays from an object into an image. Higher powered plus lenses focus the light at a sharper angle with a shorter distance between the lens and the focused image behind the lens. Lower powered plus lenses focus the light at a longer distance behind the lens.

THE CAMERA MODEL OF THE EYE

The eye is like a camera in many ways. Light enters the camera lens as diverging light from the original object. The glass of the plus lens has a different index of refraction than air; therefore, light is redirected, or refracted, into a converging pattern and focuses at a particular distance from the back of the lens that coincides with the camera sensor.



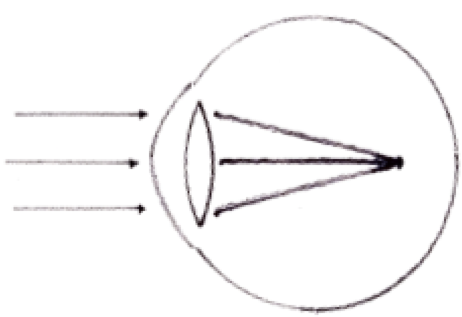
Light entering the eye is refracted by the eye's plus lens system to a point that coincides with the retina.

Likewise, diverging light enters the eye and is refracted by the cornea and lens, which is the eye's plus-powered lens system. The light then converges and focuses on the eye's sensor, the retina. Unlike a camera's flat, square sensor, the retina is curved in a spherical shape.

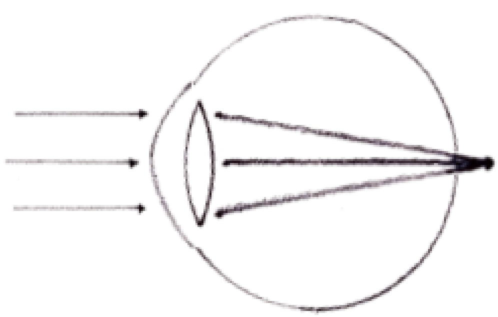
The lens of a camera needs to be focused differently depending on the distance an object is from the lens. Further objects need less plus power than close objects do to focus on the sensor. The distance between the lens and sensor remains constant. To compensate for different distances to the object, the lens system is adjusted to change the amount of plus power. The eye compensates in a similar manner by changing the lens' shape and surface radius of curvature. Like a camera, an eye's lens system has a limit of maximum and minimum available positive refractive powers. If an amount of plus power outside of that range is required, the image cannot be completely focused or clear.

REFRACTIVE ERROR

Under normal conditions, light focuses exactly on the retina to form a clear and crisp image. When an eye's optical lens system is "relaxed" to the lowest plus power setting, objects at an "infinite" distance (considered to be 20 feet or more) will appear clear. Any object closer than 20 feet will require additional plus power, with more plus required for shorter object distances correspondingly.



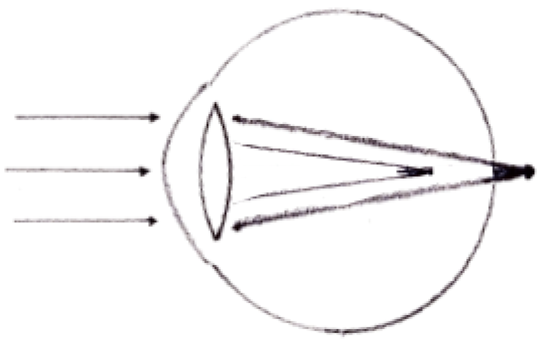
Myopia causes the light rays to focus in front of the retina.



Hyperopia causes the light rays to focus in front of the retina.

Some eyes are "perfectly calibrated", meaning when the lens system is fully relaxed, distant objects are clear. This situation is called emmetropia. Other eyes' fully relaxed lens systems have too much or too little plus power to focus light exactly on the retina. This is called refractive error. In the case of excessive plus power, light from a distant object will focus clearly *in front* of the retina and produce a blurry image by the time the light interacts with the retina. This is termed near-sightedness, or myopia. When there is insufficient plus power, light from a distant object will cause the light to focus clearly *behind* the retina, and the unfocused light at the retina will create a blurred image. This is termed far-sightedness, or hyperopia.

Because hyperopic eyes have insufficient plus power, additional plus power can be added to the lens system by placing a plus-powered spectacle or contact lens in front of the eye. Myopic eyes have excessive plus power, therefore adding a negatively-powered spectacle or contact lens will reduce the overall plus amount of the lens system. Both of these situations result in incoming distant light to be focused clearly on the retina.



Astigmatism causes the light rays in perpendicular axes to focus at two different points: both in front of the retina, both behind the retina, or one in front and one behind the retina.

A more complex situation exists in the case of astigmatism: having different amounts of refractive error in different axes (or meridians). For example, an eye's lens system can have a certain amount of refractive error in the horizontal axis while having a different refractive error in the vertical axis. This is most commonly caused by a difference in surface curvature in perpendicular axes of the cornea or lens since radius of curvature is one of the two factors that affect refractive power. These types of refractive errors are corrected by using an additional lens that correspondingly compensates with two different powers in two corresponding axes.

Lastly, as a person ages, their lens becomes more rigid and loses the ability to change the curvature of its surface. It essentially becomes frozen in a fully relaxed state prohibiting additional plus power to be added inherently to the lens system to compensate for nearer objects. This condition is called presbyopia. To compensate, a lens is added in front of the eye, when needed, that provides the required amount of additional plus power. These lenses are referred to as reading glasses, bifocals, trifocals, or progressive-addition lenses.