
Learning Objectives

At the end of this unit you should be able to;

- Identify converging and diverging lenses from their curvature
- Construct ray diagrams for converging and diverging lenses in order to locate the image
- Distinguish between real and virtual images
- Calculate the magnification of a lens
- Identify which type of image is produced by a diverging lens, and which type is produced by a converging lens given the position of the object
- Use the lens formula and relate object / image distances to focal lengths
- Identify the major parts of the eye and describe the function as an optical system, including how the eye forms an image
- Identify and explain short and long sightedness, and select the appropriate lenses to correct these sight defects
- Calculate the power or focal length of a lens using the lens power equation

Introduction.

Reflection in a mirror, the photographs formed through focusing an image through a lens onto photographic film, the view through binoculars or a pair of glasses are all examples of images, some of which are real and some of which are virtual. In each case, the image being studied appears to be in a different location than the object, or a different size. The eye for example focuses an upside down image of the world onto the retina, which the brain automatically flips the right way up whilst processing.

An image is formed when the direction of light from an object is altered by reflection, refraction, or both, such that the light rays seem to come together or emanate from the image. To understand the formation of real and virtual images the ray model of light is required together with the laws of reflection and refraction, and some simple geometry.

Key Facts and Principles.

The purpose of a lens is to change the direction of the light that it transmits through the process of refraction. The *radius of curvature* of the lens and the *refractive index* of the lens material dictates how much the lens changes the propagation direction of light.

- The amount a light ray's direction is changed by a lens depends on the angle of incidence, the radius of curvature, and the refractive index of the lens material.
- Rays that spread out from a point source are **divergent** (they diverge).
- Rays that come together at a point are **convergent** (they converge).
- The process of converting divergent or convergent rays into parallel rays is **collimation**.
- The point at which rays meet after converging from a converging lens is the **focal point** of the lens.
- A line normal to the surface of the lens passing through its center is the **optic axis**.

For the main part, lenses can be divided into two categories, **converging** and **diverging** lenses.

- A converging lens is also known as a **convex lens**, and makes parallel rays converge at a focal point. The distance between the centre of the lens and the focal point *F* is the **focal length**.
- A diverging lens is also known as a **concave lens**. A concave lens makes parallel rays **diverge**. The focal point *F* and focal length for a concave lens is found by tracing the emerging rays back through the lens to the point at which they intersect.

To consider the formation of an image using a lens, the objects height must be considered. Objects with height are known as extended objects. On a ray diagram, extended objects are represented by an arrow representing object height and orientation. For an extended object that is positioned **outside the focal length** of a converging lens;

- *A real image is formed*
 - *The image is inverted*
 - *The image is diminished*
-

For an extended object that is positioned ***inside the focal length*** of a converging lens;

- *A virtual image is formed*
- *The virtual image must be viewed by looking through the lens*
- *The virtual image is the right way up*
- *The virtual image is magnified*
- *The lens acts as a magnifying glass*

The ***magnification*** produced by the lens is the ratio of the image height and the object height and has no units.

- Magnification greater than 1 – image is larger than the object
- Magnification less than 1 – image is smaller than the object
- Magnification equal to 1 – image is the same size as the object

The amount an object is magnified can be found using;

$$\text{magnification} = \frac{\text{image height}}{\text{object height}}$$

or in symbols

$$m = \frac{h_i}{h_o}$$

where m = magnification

h_i = image height

h_o = object height

The image formed from a concave converging lens is virtual when the object is within a focal length and real when the object is outside the focal length. For a diverging lens however, the image is ***always*** virtual since on the real image side of the lens, the rays are always diverging. For a ***diverging lens***;

- *The image is always virtual*
 - *The image is always upright*
 - *The image is always smaller than the object*
-

The lens maker's formula may be used to relate focal lengths of both converging and diverging lenses to object and image distances:

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{f}$$

where

R_1 = the distance from the object to the lens

R_2 = the distance from the lens to the image

f = focal length

To use this formula, the '*real is positive*' convention must be followed;

- Objects distances are assigned positive values of R_1
- Real image distances are assigned positive values of R_2
- Virtual image distances are assigned negative values of R_2
- For converging (convex) lenses the focal length is positive
- For diverging (concave) lenses the focal length is negative

The human eye is roughly 2.5cm in diameter and nearly spherical, but the front is more sharply curved than the back, with the following main parts forming the optical system;

Cornea – A tough transparent membrane that acts as a protective covering. Most of the refraction of the light that enters the eye occurs at the air-cornea interface and provides 65% of the eye's focusing power.

Aqueous humor - A fluid filled sack separating the cornea and the lens.

Lens - A sack of fibrous jelly that is harder in the middle and becomes progressively softer towards the outside. The Jelly like composition allows the lens to be reshaped, providing a variable focal length.

Ciliary muscle – Muscle that is attached to the lens by ligaments. Contraction and relaxation of the ciliary muscles adjust the focal length of the lens.

Vitreous humor - A thin, jelly like transparent fluid filling and providing structural integrity to the main cavity separating the lens and the retina.

Retina - The light sensitive surface at the back of the eye onto which the real and inverted image is focused. The retina detects light and transmits electrical signals proportional to the light detected to the brain via the *optic nerve*.

Iris - Located in front of the lens the iris forms a variable aperture called the **pupil**. The iris adjusts the amount of light entering the eye.

For an object to be viewed, the image of the object is projected onto the retina. For the image to be *sharp*, it must be projected *exactly* onto the retina.

The eye cannot adjust the position of the focal point by adjusting the lens – image distance. Instead, it copes with the varying distances to objects by adjusting the focal length of the lens. Sight defects occur when the lens does not focus the image of the object directly onto the retina.

- Long sightedness - The focal point of the lens is behind the retina, leaving a blurred and out of focus image on the retina due to the eyeball being too short or the cornea too curved. Corrected using a converging lens that adds power to the eye's lens, making the rays from the object diverge less.

Short sightedness - Parallel rays from the distant objects are focused in front of the retina, because the ciliary muscles cannot make the lens thin enough to place the focal point at the retina. Corrected using a diverging lens in front of the eye to diverge the rays slightly in front of the eye.

The power of the corrective lens is given by;

$$\text{Power} = \frac{1}{\text{focal length}}$$

or in symbols

$$P = \frac{1}{f}$$

where

P = Power of the lens

f = focal length

The unit of lens power is the *diopetre* (D) or m^{-1} .

The type of lens used is signified as a **positive** number for a **converging** lens, and a **negative** number for a **diverging** lens.

Glossary

Collimate – To make diverging or converging rays parallel.

Concave – Having a surface curving inward or hollowed inward, as the interior of a circle or sphere

Convergent – To tend toward a point of intersection

Convex – Having a surface or boundary that curves or bulges outward, as the exterior of a circle or sphere.

Divergent– Drawing apart from a common point.

Diopetre (unit)– The unit of lens power, equivalent to 1/metre.

Inverted –Turned upside down.

Lateral Inversion – Turned back to front but remaining upright.

Optical – Of or relating to visible light.

Optically Transparent – Non absorbing, resulting in a clear substance that allows the passage of light without loss.

Planar – A plane forming the common boundary between two parts of matter or space. A flat surface, with two-dimensional characteristics.

Radius of Curvature– The radius of a circle that touches a curve at a given point and has the same tangent and curvature at that point.

Surface Normal – The normal vector, often simply called the "normal," to a surface, a vector that is perpendicular to the surface at a given point.

Virtual image – An optical image formed by the apparent divergence of rays from a point, rather than their actual divergence from a point.
