Chapter 23

The Refraction of Light: Lenses and Optical Instruments

Lenses

Converging and diverging lenses.

Lenses refract light in such a way that an image of the light source is formed.

With a **converging lens**, paraxial rays that are parallel to the principal axis converge to the focal point, F. The focal length, f, is the distance between F and the lens.



Two prisms can bend light toward the principal axis acting like a crude converging lens but cannot create a sharp focus.

Lenses

With a **diverging lens**, paraxial rays that are parallel to the principal axis appear to originate from the focal point, F. The focal length, f, is the distance between F and the lens.



Two prisms can bend light away from the principal axis acting like a crude diverging lens, but the apparent focus is not sharp.

Lenses



Converging and diverging lens come in a variety of shapes depending on their application.

We will assume that the thickness of a lens is small compared with its focal length → Thin Lens Approximation

The Formation of Images by Lenses

RAY DIAGRAMS. Here are some useful rays in determining the nature of the images formed by converging and diverging lens.

Since lenses pass light through them (unlike mirrors) it is useful to draw a focal point on each side of the lens for ray tracing.



IMAGE FORMATION BY A CONVERGING LENS



When the object is placed further than twice the focal length from the lens, the real image is inverted and smaller than the object.

This is the configuration for a camera. The focal length of the lens system of a camera must be adjusted for a particular object distance so that the image distance is at the location of the film and thus the real image on the film is sharp (focused).

IMAGE FORMATION BY A CONVERGING LENS

 $2f > d_{o} > f$



When the object is placed between F and 2F, the real image is inverted and larger than the object.

This is the configuration for a projector. Since you normally want the real image on the screen to be upright, the object (film or slide) is placed upside down in the projector.

The Formation of Images by Lenses

IMAGE FORMATION BY A CONVERGING LENS



When the object is placed between F and the lens, the virtual image is upright and larger than the object.

This is the configuration for a magnifying glass. The magnifying glass must clearly be positioned so that the object distance is less than its focal length

IMAGE FORMATION BY A DIVERGING LENS

all d_{0} 1



A diverging lens always forms an upright, virtual, diminished image.



These equations are identical to the mirror equations!

The sign conventions are similar to those for mirrors, but there are a few differences.....

Summary of Sign Conventions for Lenses f is + for a converging lens. f is - for a diverging lens. d_o is + if the object is to the left of the lens.

 d_o is – if the object is to the right of the lens.*

 d_i is + for an image formed to the right of the lens (real image). d_i is – for an image formed to the left of the lens (virtual image).

> m is + for an upright image. m is – for an inverted image.

* can occur in the case of imaging with more than one lens.

Example. The Real Image Formed by a Camera Lens A 1.70-m tall person is standing 2.50 m in front of a camera. The camera uses a converging lens whose focal length is 0.0500 m. (a)Find the image distance and determine whether the image is real or virtual. (b) Find the magnification and height of the image on the film.

(a)
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{0.0500 \text{ m}} - \frac{1}{2.50 \text{ m}} = 19.6 \text{ m}^{-1}$$

 $d_i = 0.0510 \text{ m}$ real image, since $d_i > 0$
 $for all image = \frac{1}{0.0510 \text{ m}} = -0.0204$ image inverted, since $m < 0$
 $m = -\frac{d_i}{d_o} = -\frac{0.0510 \text{ m}}{2.50 \text{ m}} = -0.0204$ image inverted, since $m < 0$
and reduced since $|m| < 1$
 $h_i = mh_o = (-0.0204)(1.70 \text{ m}) = -0.0347 \text{ m}$

Example. The Virtual Image Formed by a Diverging Lens An object is placed 7.10 cm to the left of a diverging lens whose focal length is f = -5.08 cm. (a) Find the image distance and determine whether the image is real or virtual. (b) Obtain the magnification.

(a)
$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{(-5.08)} - \frac{1}{7.10} = -0.338 \text{ cm}^{-1}$$
$$d_i = -2.96 \text{ cm} \quad \text{virtual image, since } d_i < 0$$
(b)
$$m = -\frac{d_i}{d_o} = -\frac{(-2.96)}{7.10} = 0.417 \quad \text{image upright, since } m > 0$$
and reduced since $|m| < 1$

Example of a two-lens system: Two converging lenses each of focal length 20 mm are separated by 30 mm from each other. An object is placed at 28 mm in front of the first lens. Find the final image distance and final magnification of this two-lens system.





Chapter 24

Interference and the Wave Nature of Light

Huygens' principle



Huygens' principle

Every point on a wave front acts as a source of tiny wavelets that move forward with the same speed as the wave; the wave front at a latter instant is the surface that is tangent to the wavelets.

Diffraction is the bending of waves around obstacles or the edges of an opening.

Listener hears sound around the corner

Huygens' principle



(a) Smaller value for λ/W , less diffraction.



(b) Larger value for λ/W , more diffraction.

The extent of the diffraction increases as the ratio of the wavelength to the width of the opening increases since there is less cancelling from adjacent Huygens' wavelets.

