

The Reflection of Light: Mirrors

1 – Plane Mirrors

The laws of reflection and refraction can be developed using a geometric method proposed by Huygens in 1678. His wave model is adequate for understanding many practical aspects of the propagation of light.

Huygens principle:

All points on a given wavefront are taken as point sources for the production of spherical secondary waves. The new position of the wavefront after some time is the surface tangent to the spherical waves.

Wavefront: Surface passing through those points of a wave that have the same phase and amplitude.

Ray approximation: The rays of a given wave are straight lines perpendicular to the wavefronts. In the ray approximation one assumes that a wave moving through a medium travels in a straight line in the direction of its rays.

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We now study the formation of images. Images can be formed by either reflection or refraction of light. We will start discussing the formation of images by reflection using mirrors. We begin by examining the simplest possible mirror, the plane mirror.

- Consider a point light source (=object) placed at a point O at a distance d_o in front of a mirror. d_o is called the **object distance**.
- Light rays leave the source and are reflected by the mirror. To the observer, the rays appear to come from a point, I , behind the mirror. Point I is called the **image** of the object at O . The distance d_i is called the **image distance**.
- *Images are formed at the point where rays of light actually intersect or at which they appear to originate.*

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- Images are classified as **real** or **virtual images**. A **real image** is one where light actually intersects with the image. A **virtual image** is one where the light does not really pass through the image, but just appears to come from that point.
- The image of a plane mirror is a virtual image.
- The image formed by an object placed in front of a plane mirror has the following properties:
it is as far behind the mirror as the object is in front of the mirror:

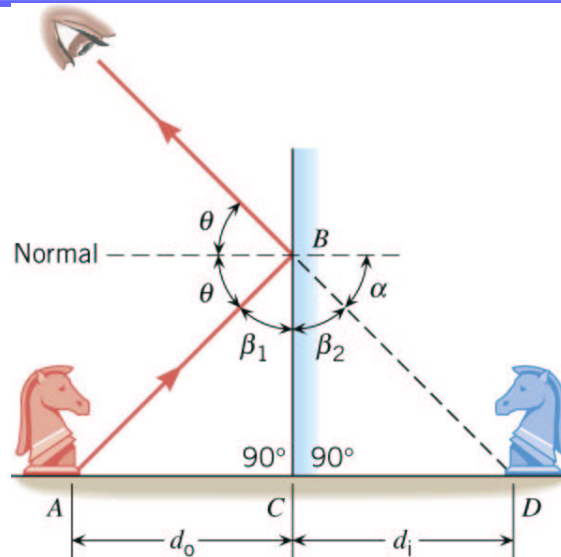
$$d_o = d_i$$

it is of the same size as the object, *i.e* the **magnification** of the mirror is

$$m = \frac{\text{image height}}{\text{object height}} = \frac{h_i}{h_o} = 1 \quad (1)$$

and it is upright.

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Experiments show that the angle of reflection equals the angle of incidence:

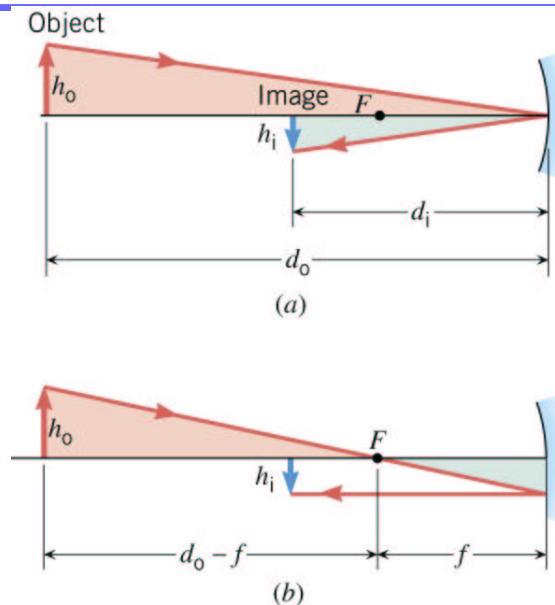
$$\theta_i = \theta_r \quad (2)$$

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2 – Images formed by Spherical Mirrors

- **Spherical Mirror:** Mirror which has the shape of a segment of a sphere.
- If the light is reflected from the inner, concave surface it is called a **concave mirror**.
- If the light is reflected from the outer, convex surface it is called a **convex mirror**.
- We use geometry to calculate the image distance d_i from the object distance d_o and the radius of curvature R of the mirror.
- By convention, these distances are measured from the midpoint of the mirror. They are positive for distances in front of the mirror and negative for distances “behind” the mirror.
- The line from the midpoint to the center of curvature, C , is called the **principal axis** of the mirror.

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- Since $\tan \theta = h_o/d_o = -h_i/d_i$, the magnification is

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad (3)$$

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- The negative sign indicates that the image is inverted (upside down). Note that in this case d_i is positive, *i.e.* the image is a real image (it is in front of the mirror, *i.e.* on the same side of the mirror as the object.)
- When the image is a virtual image, (the light appears to originate from behind the mirror), d_i is negative and m is positive, indicating that the image is upright.
- Furthermore,

$$\tan \alpha = \frac{h_o}{d_o - R} = -\frac{h_i}{R - d_i}$$

implying

$$\frac{h_i}{h_o} = -\frac{R - d_i}{d_o - R}$$

Comparison with Eq.(3) then gives the so-called **mirror equation**:

$$\boxed{\frac{1}{d_o} + \frac{1}{d_i} = \frac{2}{R}} \quad (4)$$

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- If the object is very far from the mirror, *i.e.* $d_o \gg R$, $1/d_o \approx 0$ and $d_i \approx R/2$. In this special case the image point is called the **focal point**, F , and the image distance is the **focal length**, f , where

$$f = \frac{R}{2}$$

The mirror equation can be expressed in terms of the focal length:

$$\boxed{\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}} \quad (5)$$

- For a **convex mirror** the image is always virtual (d_i is negative) and upright (m is positive). The focal length f is **negative**, *i.e.* the focal point is “behind” the mirror.

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3 – Ray Diagrams for Mirrors

- The positions and sizes of images formed by mirrors can be also determined by constructing *ray diagrams*. The construction tells us the overall nature of the image.
- To make a ray diagram, one needs to know the position of the object, and the location of the center of curvature (point C).
- To locate the image of a mirror, 3 rays are constructed:

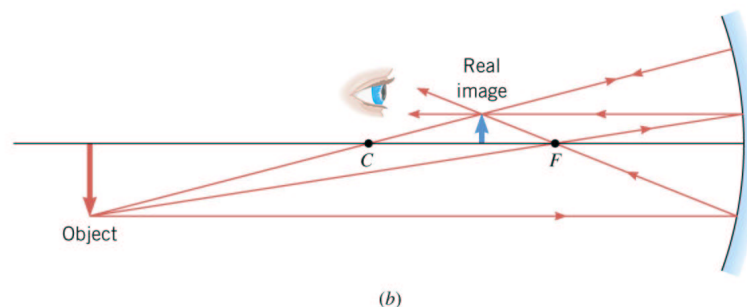
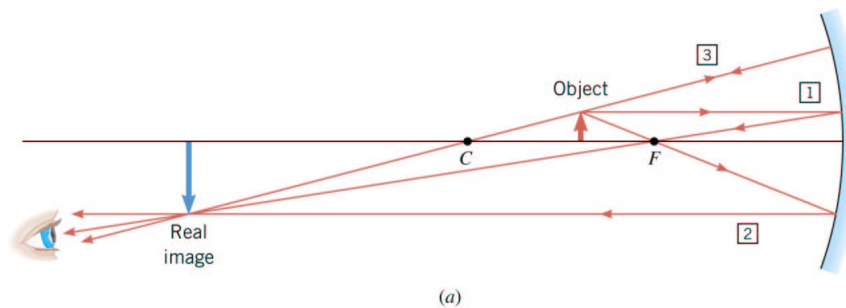
Ray 1 is drawn parallel to the principal axis and is reflected back through the focal point F .

Ray 2 is drawn through F and thus is reflected back parallel to the principal axis.

Ray 3 is drawn through C .

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- The intersection of any *two* of these rays at a point locates the image. All three rays have to intersect at the same point.



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- For a concave mirror, when the object is between the focal point and the mirror, the image is virtual and upright. Otherwise the image is real and up-side-down.
- For a convex mirror, as the distance of the object from the mirror increases, the virtual image shrinks and approaches the focal point.

