PHY 171
Lecture 6
(*January 18, 2012*)

Light

Throughout most of the next 2 weeks, we will be concerned with the *wave properties* of light, and phenomena based on them (interference & diffraction).

Light also can be modeled as if it is made of particles (e.g., for the photoelectric effect) – those of you in Physics and Engineering will see this in PHY 270.

But, there is yet another way of studying light that has consequences for the real world (building mirrors and lenses). This is what we will study first, and we will do it in a more experiential sitting than we have been having so far.

Chapter 35: Geometric Optics

Ray model of light

Ray model assumes that light travels in straight-line paths called light rays.

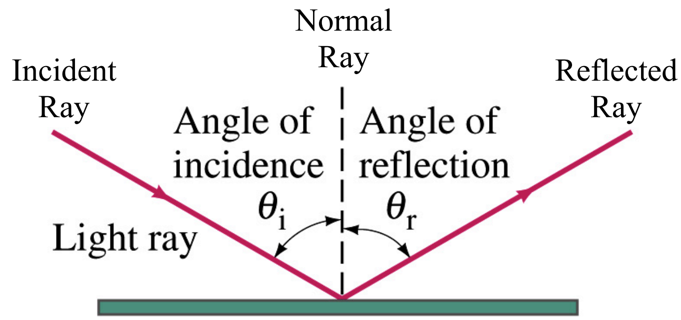
- A light ray is an idealization used to represent an extremely narrow beam of light.
- Ray model successful in accounting for reflection, refraction, and the formation of images by mirrors and lenses.

Demo: Ray model

We looked at a demonstration of the straight-line path of a laser beam illuminated by scattering off of gas particles sprayed from a can.

In this lecture, we will learn about reflection from plane and curved surfaces. In particular, we will learn about the paths of light reflected from plane mirrors and convex and concave mirrors. We will also learn about the images formed in these mirrors, and whether these images are real or virtual (the difference is explained below), upright or inverted, enlarged or diminished in size, and formed behind the mirror or in front.

Reflection



We saw a demo in Blackboard Optics.

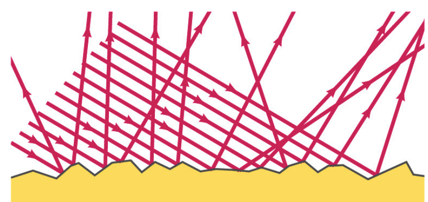
The ***normal ray*** is a ray at right angles to the reflecting surface. If light is incident perpendicular to the mirror surface along the normal ray, it will be reflected back along the same path (as shown in the figure).

Laws of Reflection

1. The incident ray, the normal ray at the point of incidence, and the reflected ray all lie in the same plane.
2. The angle of incidence is equal to the angle of reflection.

Diffuse Reflection

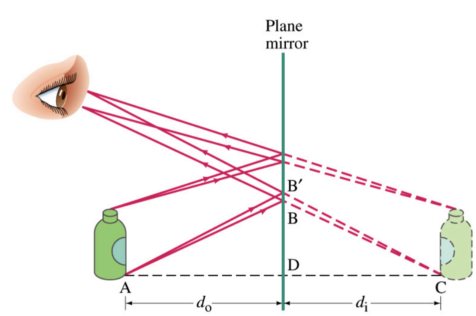
When light is incident on a rough surface, it is reflected in all directions. This is known as ***diffuse*** reflection.



Note that the laws of reflection ***still hold*** at each small section of the surface. It is only because each small section of the surface is angled differently for a rough surface that for a parallel beam of light, the reflected rays go off in different directions (as seen in the figure).

To distinguish it from diffuse reflection, the reflection from regular (mirrored) surfaces is sometimes called "regular" or "specular" reflection.

Formation of Images in a Plane Mirror



A bottle is placed in front of a plane mirror. Rays of light from the bottle to the mirror are reflected as shown, in accordance with the laws of reflection stated above. They are then viewed at the position indicated by the eye. Our eyes interpret any rays entering it as having traveled in a straight-line path. So, rays from the object that are reflected from the mirror and enter the eye are traced back by the eye along a straight line, and appear to come from a point behind the mirror. This point behind the mirror is the location of the image.

The image formed by a plane mirror is called a *virtual* image because the light rays do not actually pass through the image position – they only appear to be coming from the image position because the brain interprets any light entering our eyes as having come in a straight line path.

> The designation "virtual image" distinguishes the image from a real image formed by curved mirrors and lenses in which the light actually passes through the image position — therefore, if you put a screen at the location of a real image, the image can be viewed on the screen (you have experienced the power of projecting a real image many times before, of course — in a cinema theater).

Note that instead of drawing a bottle every time, we will simply be ***drawing an arrow*** to indicate the object.

Characteristics of Plane Mirror images

Think about what you see when you look in a plane mirror.

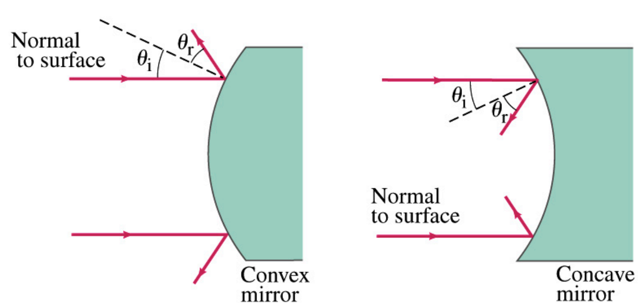
- The image is the same size as the object (your image in the mirror is the same size as you).
- The image is upright (if you're standing up, your image in the mirror is also standing up).
- The image distance is equal to the object distance (if you move toward the mirror, your image in the mirror will appear to move toward you). It is easy to prove from the congruent triangles ABD and CBD in the figure above (on the previous page) that for image formation in plane mirrors,

$$\text{image distance, } d_i = \text{object distance, } d_o$$

- The image is laterally inverted (your right is left in the mirror).

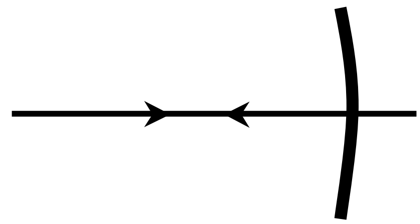
Spherical Mirrors

Now, observe how curved surfaces reflect light – notice that the laws of reflection stated above are still valid. The rays just go off in different directions due to the local curvature of the surface.



When the surface caves inward, as shown on the right, we call it a concave mirror. When the surface curves outward, as shown on the left, we call it a convex mirror.

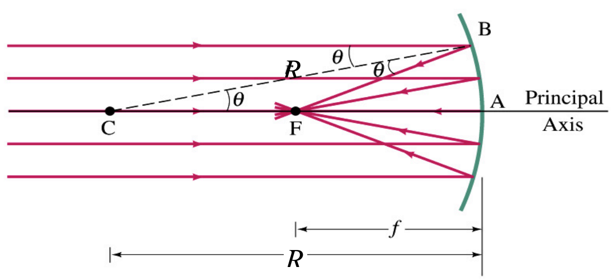
Mirrors such as the ones shown on the previous page are carved out of larger spheres. The center of the sphere from which the mirror has been carved is called the **center of curvature**, a point we will mark in our figures and ray diagrams as *C*. If you know your geometry, you will realize immediately that any ray of light passing through the center of curvature is a normal to the mirror. Therefore, it will always be reflected back along itself.

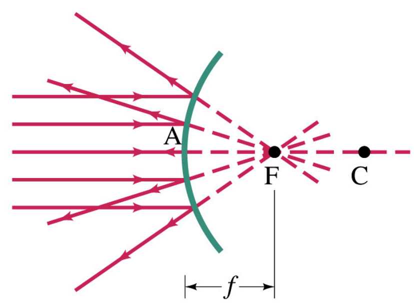


Principal axis: Of all the rays passing through the center of curvature that get reflected back along their own path, one in particular is of great importance for us in locating the position of the image. This is the ray that is perpendicular to the curved surface of the mirror at its geometric center, and it is called the principal axis. A ray of light traveling along the principal axis will be reflected back along the principal axis after reflection from the mirror. This is true for both concave mirrors (shown in the figure on the right) and convex mirrors.

Focus: If a beam of rays parallel to the principal axis is reflected from a concave mirror, the rays will meet (approximately) at a point, called the focus of the mirror. This is the point *F* marked in the figure below.

> If the curvature of the mirror is small (i.e., the mirror is small compared to its radius of curvature *R*), the focus will be one well-defined point. Otherwise, rays incident on the mirror further away from its center will come to a focus at a slightly different point compared to rays incident closer to the center





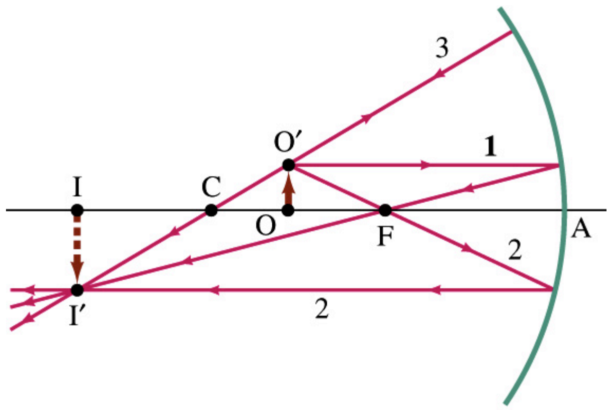
Focus for convex mirrors: Parallel rays incident on a convex mirror will diverge after reflection — however, a focus can still be defined for a convex mirror: if the diverging rays are traced back behind the convex mirror, they will appear to originate at one common point. This point is called the focus of the convex mirror, and is marked as *F* in the figure on the right.

Focal Length: The distance from the focus to the geometric center of the mirror (i.e., along the principal axis) is called the focal length *f* of the mirror. This is marked in both figures above (for the concave as well as the convex mirror) as *f*.

If *R* is the radius of curvature of the concave or convex mirror (e.g., the distance along the principal axis from the center of curvature to the mirror surface), then we can show from geometry that the focal length, $f = R/2$.

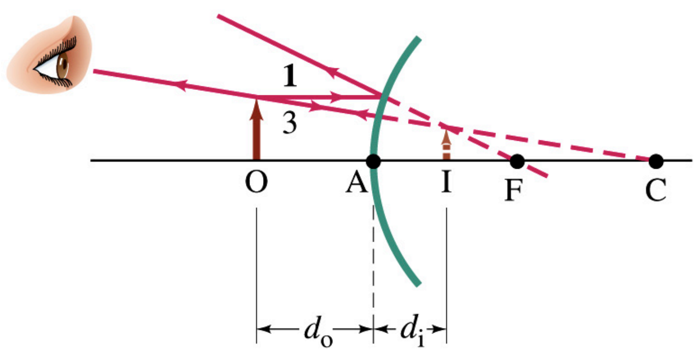
Locating Images in Concave Mirrors - 3 rules

1. A ray parallel to the principal axis will pass through the focus after reflection from a concave mirror. *This is shown by ray 1 in the figure below.*
2. A ray passing through the focus of a concave mirror will become parallel to the principal axis after reflection. *This is shown by ray 2 in the figure below.*
3. A ray passing through the center of curvature of the mirror will be perpendicular to the mirror — such a ray will be reflected back along its incident path after reflection. *This is shown by ray 3 in the figure below.*



Locating Images in Convex Mirrors - 3 rules

1. A ray parallel to the principal axis will appear to originate from the focus after reflection from a convex mirror. *This is shown by ray 1 in the figure below.*
2. A ray aimed toward the focus of a convex mirror will become parallel to the principal axis after reflection.
3. A ray aimed toward the center of curvature of the convex mirror will be perpendicular to the mirror — such a ray will be reflected back along its incident path after reflection. *This is shown by ray 3 in the figure below.*



Mirror Equation for Concave and Convex Mirrors

From geometry, we can easily show that

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

where d_o is the ***object distance*** (distance of the object from the mirror, usually measured along the principal axis)

d_i is the ***image distance*** (distance of the image from the mirror, usually measured along the principal axis)

and f is the ***focal length*** of the mirror

This equation is applicable to both concave and convex mirrors, provided the appropriate sign conventions are used — see below.

Magnification

The magnification of the image is given by

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

The minus sign above is inserted as part of the sign convention.

Sign Convention

- When object, image, or focus is on the reflecting side of the mirror, corresponding distance is positive. Therefore, f is (+) for a concave mirror.
- If any of these points (object, image, or focus) is behind the mirror, corresponding distance is negative. Therefore f is (−) for a convex mirror.
- Consider object height as positive (always). Then, image height is positive if image is upright, negative if inverted.

From these rules, we see the need for the minus sign in the equation for $m = -d_i/d_o$. For all real images in a concave mirror, both d_o and d_i will be positive — therefore, the (−) sign for m will indicate that the image is inverted, compared to the object.

In future worksheets, we will draw upon several of the above ideas, namely, a geometric method to locate the position of the image, and a comparison to the image distance located mathematically using the formulas written above.