# 3.1: Mirrors

## Tutorial 3.1: Reflection I

In many cases plane waves will travel in a straight line, reflecting off of objects and surfaces at the same angle that they strike the surface. This is called the **law of reflection** and is true for sound waves as well as light as long as the surface is smooth. In these cases we can treat the wave as a straight line or ray which is perpendicular to the wave front. **Geometric** (or ray) **optics** is the study of light in cases where the wave travels in a straight line except for reflection and refraction (treated later).

By smooth we mean that the roughness of the surface has variations that are smaller than the wavelength of the wave. If the surface is smooth enough a group of parallel rays will all reflect in the same direction. This is called **specular reflection**. When the surface is rough relative to the wavelength, although individual rays still obey the law of reflection they end up not being parallel after being reflected. This is called **diffuse reflection**.

For light, with very small wavelengths, this means the surface must be very smooth for specular reflection. For larger electromagnetic waves, such as microwaves, digital TV signals and radio waves, specular reflection occurs even when the surface is relatively rough. This is why mirrors are used in optical telescopes but radio telescopes and Direct TV dishes do not need to be as smooth as a mirror.

The simulation below allows for a brief exploration of specular reflection. The mirror in each case in in the center and everything to the right is behind the mirror (virtual). These examples are for light reflecting off of mirrors, the same behavior occurs for any wave (sound for example) if the surface is smooth relative to the wavelength. The units of height, $h$, and distance, $d$, are arbitrary ( $\mathrm{cm}$, inches, etc.).

### Mirrors

#### Questions:

**Exercise 3.1.1**

The simulation starts with a flat mirror, an object on the left (a candle) and the candle's image (shown on the right). Three real rays (white arrows) are shown leaving the object and reflecting off the mirror. Carefully describe each ray. What does the parallel ray do when it reflects off the mirror? What does the ray that goes to the center of the mirror do when it reflects?

**Exercise 3.1.2**

The small protractor can be dragged to different locations and the arrow tip can be moved to change the angle. Use it to measure the incident and reflected angles (they are measured from the perpendicular, not the surface of the mirror). What are the incident and reflected angles for the ray going from the object to the center of the mirror? Is the law of reflection obeyed?

**Exercise 3.1.3**

Our eyes and brain do not percieve the rays as reflecting. Instead, our brains percieve the reflected rays as coming from behind the mirror (the magenta arrows) from an imaginary or **virtual** image behind the mirror. The object can be moved using the mouse. Does the size of the image change if the object is moved back and forth?

**Exercise 3.1.4**

Now choose the convex mirror button. Move the object back and forth. Describe what happens to the image as the object moves back and forth. What happens to a parallel ray when it reflects? What happens to a ray going to the center of the mirror? The red dot on the right is the focal point of the mirror and is $1/2$ the radius of curvature of the mirror. What happens to a ray that starts on the left and heads towards the focal point on the other side; how does it reflect?

## Exercise 3.1.5

Use the protractor to measure the incident and reflected angles for the ray striking the center of the mirror for the convex case. Are the equal? The other rays also obey the law of reflection but the mirror surface at those locations is not perpendicular to the $x$-axis. Place the protractor at the location where the top ray strikes the mirror and rotate the arrow to point directly away from the radius of curvature (turquoise dot). This is the direction of a perpendicular to the mirror and should fall precisely between the incoming and outgoing rays. What is the angle?

## Exercise 3.1.6

For the flat and convex mirror, does the size of the object change the laws of reflection? Describe what you see.

## Exercise 3.1.7

Now click on the concave mirror button. Slide the object back and forth, moving it from very far away from the mirror to very close. Describe where the image is, its size relative to the object and orientation (Hint: There are three different cases; Closer than the focus; further away than the focus but closer than twice the focal length; further away than twice the focal length.)

Images appearing behind the mirror (to the right in the simulation) are **virtual images**; we can only see them by looking into the mirror. Images appearing on the left side, in front of the mirror are **real images**. These can be seen in the mirror and can also be projected onto a screen.

## Exercise 3.1.8

For the flat mirror were the images real or virtual? Are the images for the convex mirror real or imaginary? How do you know? In which cases were the images real and virtual in the concave mirror?

## Exercise 3.1.9

Describe the three reflected rays for the case of a virtual image in the concave mirror case. Do they obey the law of reflection? Explain.

## Exercise 3.1.10

Describe the three reflected rays for the case of a real image in the concave mirror case. Do they obey the law of reflection? Do the laws of reflection change depending on the size of the object in the concave case? Explain.

## Exercise 3.1.11

Go back to the flat mirror and use the mouse to find the distance from the mirror to the object and from the mirror to the image. How are these related?

For a flat mirror the image height and image distance are the the same as the object's. For a curved mirror the relation between the distance to the object, $s$ and to the image $s^{'}$ are related to the focal length, $f$ which is equal to one half the radius of curvature of the mirror. The relationship is $1/f = 1/s + 1/s'$ where the focal length is postive for a concave mirror and negative for a convex mirror. The distance to the image will be positive if the image is real and negative if virtual.

## Exercise 3.1.12

Use the mouse to find the distance to the object and to the image for several different distances in the convex mirror case. Use these values to find the focal length, $f$ (don't for get the sign convention given in the previous paragraph).