

## Lenses

Light coming from an object can be altered if they pass through a **lens**. A lens is an optical device with two curved, non-parallel refracting surfaces. There are two types of lenses to consider: converging and diverging. A **converging lens** (convex lens) with smooth surfaces allows parallel light rays to bend toward an axis that passes through the center of the lens and to converge at a single point called the **focal point**  $f$ . The focal length for a converging lens is always a *positive* value. This is shown in **Figure 10-13a**. Because light can enter the lens from both its right and left sides, the lens has two focal points.

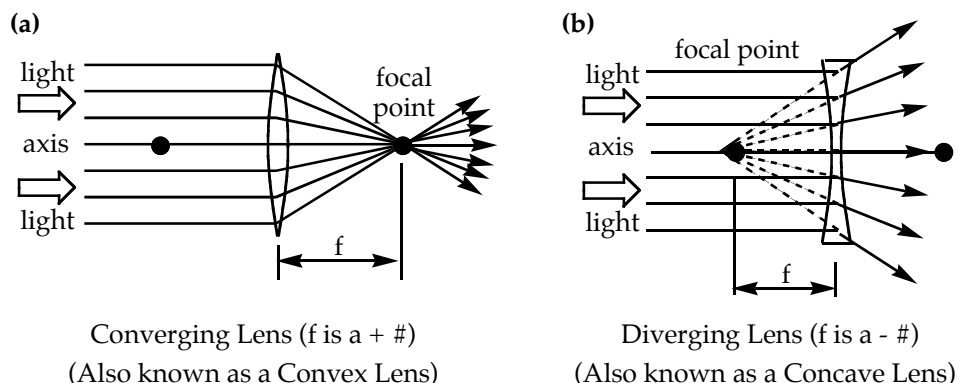


Figure 10-13

A **diverging lens** (concave lens) allows parallel light rays to move apart as they pass through the lens. As shown in **Figure 10-13b**, the focal length of a diverging lens is a **negative** value. This is because the diverging light rays appear to leave a single focal point from the side of the lens that light enters. Like converging lenses, diverging lenses will also have two focal points.

As light passes through a lens, either a real image or a virtual image can be formed. The rules for single lenses are the same as they are for single mirrors, except that the real and virtual sides are flipped and convex and concave are reversed. As was the case with mirrors, diverging systems generate smaller, upright, virtual images. Converging systems, be it lenses or mirrors, also share similar rules. Let's consider the formation of a real image using a converging lens. This can only occur if the object is outside of the focal length. An object is placed a distance  $s$  to the left of the lens, as shown in **Figure 10-14**.

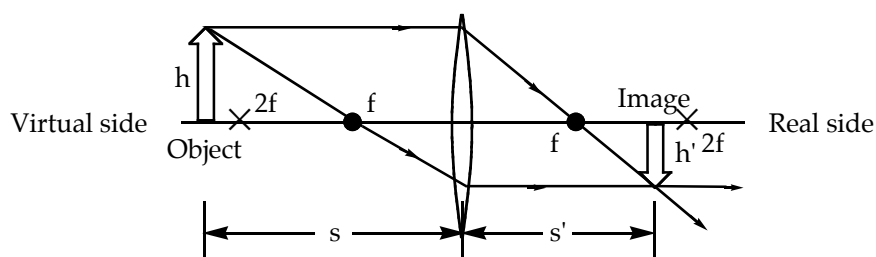


Figure 10-14

Light rays leaving this object travel in all directions, and some of them pass through the lens. Of all the rays that pass through the lens, we will focus our attention on just two of them. They pass through the lens to form an inverted image of the object at distance  $s'$  to the right of the lens. Because the light rays pass through the lens and come together to form an (inverted) image of the object, that image is called a **real image**. One property of real images is that only they can be cast upon a screen, photographic negative, or retina. Thus, lenses in cameras and eyes have focal lengths that produce real images.

Now let's consider the formation of a **virtual image** using a converging lens. This is only possible if we place our object between the focal point and the lens, as shown in **Figure 10-15**. As the light rays coming from the object pass through the lens, they will diverge on the right side. If we follow those diverging rays back through the lens (dashed lines), we find that they intersect at a point **A** to the left of the object. Since no light rays from the object intersect at that point in space, the image at that point is said to be virtual.

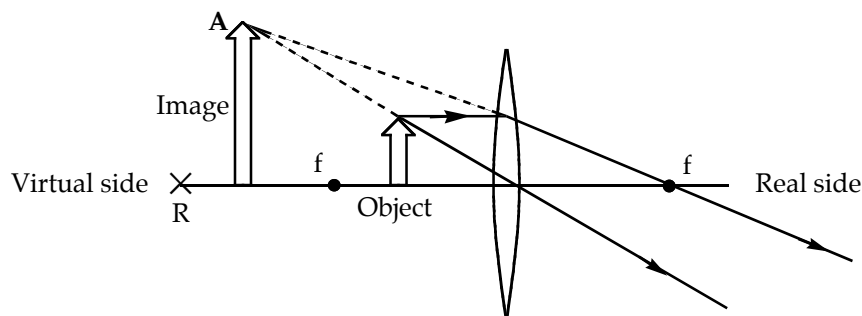


Figure 10-15

### Magnification

Suppose we wanted to know the height of our image  $h'$  relative to the height of the object  $h$  in **Figure 10-14**. This is called **linear magnification  $m$**  and is given by equation (10.10). The linear magnification value is unitless, and the conventions are listed in **Table 10-1**. In **Figure 10-8**, the object with height  $h$  is upright, pointing above the axis. The value of  $h$  is taken to be positive. The inverted image with height  $h'$  is below the axis. The value of  $h'$  is taken to be negative.

$$m = \frac{h'}{h} \quad (10.10)$$

Consider  $s$ ,  $s'$ ,  $h$ , and  $h'$  in **Figure 10-14**. We can relate these four variables to one another using geometry, where the height-to-length ratio ( $h : s$ ) is the same for both the object and the image. Both ratios need to have the same sign, so a negative sign is included. This relationship allows us to use the object and image distances to calculate the linear magnification using equation (10.11).

$$m = \frac{s'}{s} \quad (10.11)$$

The point of preparing for the MCAT is to be able to answer questions quickly. As such, let's develop a plan of attack for questions dealing with either a single lens or a single mirror. The following three-step algorithm should prove useful.

1. Identify whether the system is diverging or converging. Keep in mind that convex lenses and concave mirrors are converging systems, so you must do some work to determine whether the optic device is converging or diverging.
2. If the optic device is diverging, then the image will be smaller than the object, upright, virtual (an **SUV**), and found between the focal length on the virtual side and the optic device. If the optic device is converging, then we need to do a positional analysis to see which case it fits out of I through V.
3. Sketch a diagram of the object, optical device, and image. Double check using equation (10.12) (a shortcut version of equation (10.7)).

$$i = \frac{o \times f}{o - f} \quad (10.12)$$

**Example 10.8a**

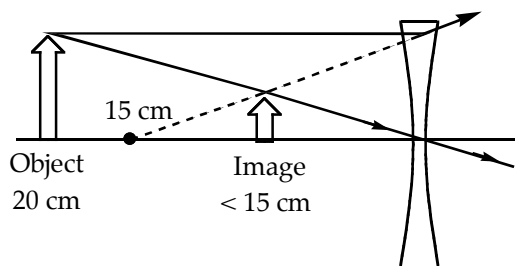
Where is an image formed when an object is 20 cm to the left of a concave lens that has a focal length of 15 cm?

- A. It is an upright, virtual image that is found 60 cm to the left of the lens.
- B. It is an upright, virtual image that is found 8.7 cm to the left of the lens.
- C. It is an inverted, real image that is found 8.7 cm to the right of the lens.
- D. It is an inverted, real image that is found 60 cm to the right of the lens.

**Solution**

Let's use the three-step method. **First** off, a concave lens is a diverging system. **Second**, because it's a diverging system, the image will be upright, virtual, smaller than the object, and found between the focal length on the virtual side and the optic device. The image distance must be less than 15 cm, eliminating choices A and D. Because it's a lens, the object is on the virtual side, so a virtual image will form to the left of the lens, eliminating choice C.

The **third** step is not necessary here, because only one answer choice remains standing. But let's consider show the step for a sense of completion.



$$i = \frac{o \times f}{o - f} = \frac{20 \times (-15)}{20 - (-15)} = \frac{-300}{35}$$

$$\frac{-300}{35} = \frac{-60}{7} = -8.\text{something}$$



**Test Tip**  
Calculation Shortcut

The best answer is choice **B**.

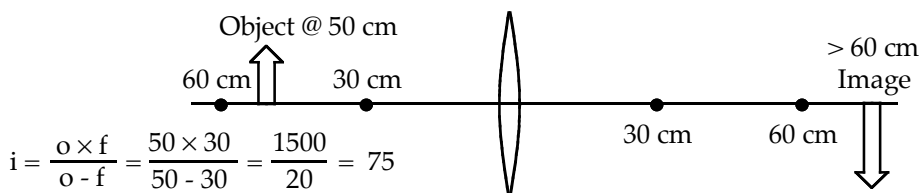
**Example 10.8b**

What is true of the image formed by an object 50 cm from a convex lens that has a radius of curvature equal to 60 cm?

- A. It is an inverted, real image that is found 75 cm from the lens.
- B. It is an inverted, real image that is found 30 cm from the lens.
- C. It is an upright, virtual image that is found 30 cm from the lens.
- D. It is an upright, virtual image that is found 75 cm from the lens.

**Solution**

Let's use the three steps listed above. First off, a convex lens is a converging system. Second, because it's a converging system, we need to determine which scenario it fits. The object is between R and f, so an inverted, real image will form beyond R. The image distance must be greater than 60 cm, eliminating choices B and C. Because the image is real, choice D is eliminated.



$$i = \frac{o \times f}{o - f} = \frac{50 \times 30}{50 - 30} = \frac{1500}{20} = 75$$



**Test Tip**  
Calculation Shortcut

The best answer is choice **A**.