

Lenses can form images much as mirrors. We define converging lenses as having a positive focal length and diverging lenses as having a negative focal length. Lenses will have We draw our object as an arrow. We draw the optical axis as the line passing through both the tail of the object and the focal points. We then draw rays of light leaving the tip of the arrow. Our eye will trace back the rays to the point from which they appear to emanate. This is the tip of the image.

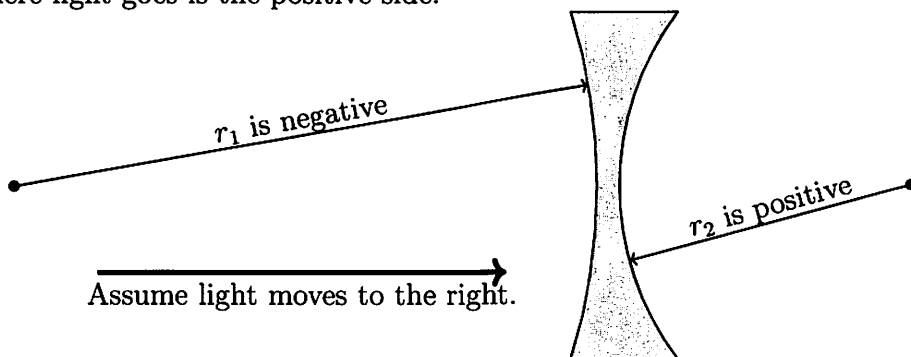
- For a converging lens, rays that are parallel to the optical axis bend to pass through the focal point on the side of the lens opposite the object. For a diverging lens, that are parallel to the optical axis bend as if they are diverging from the focal point on the same side as the object.
- For a converging lens, rays that pass through the focal point on the same side as the object bend to become parallel to the optical axis. For a diverging lens, rays that are headed towards the focal point on the opposite side of the lens bend to become parallel to the optical axis.
- Rays that pass through the center of the lens continue undeflected.

$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ and $m = -\frac{s'}{s}$ are still true. Now, real images with a positive image distance will be located on the side of the lens opposite the object. Virtual images with a negative image distance will be located on the side of the lens opposite the object.

The focal length of a lens can be determined via the lensmaker's equation:

$$\frac{1}{f} = \left(\frac{n}{n_{\text{air}}} - 1 \right) \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

Here n is the index of the lens material and we assume that the lens is in air. r_1 is the radius of curvature of the first surface encountered by the light while r_2 is the radius of the second. As always, we can use a sign convention in which the side where light goes is the positive side.



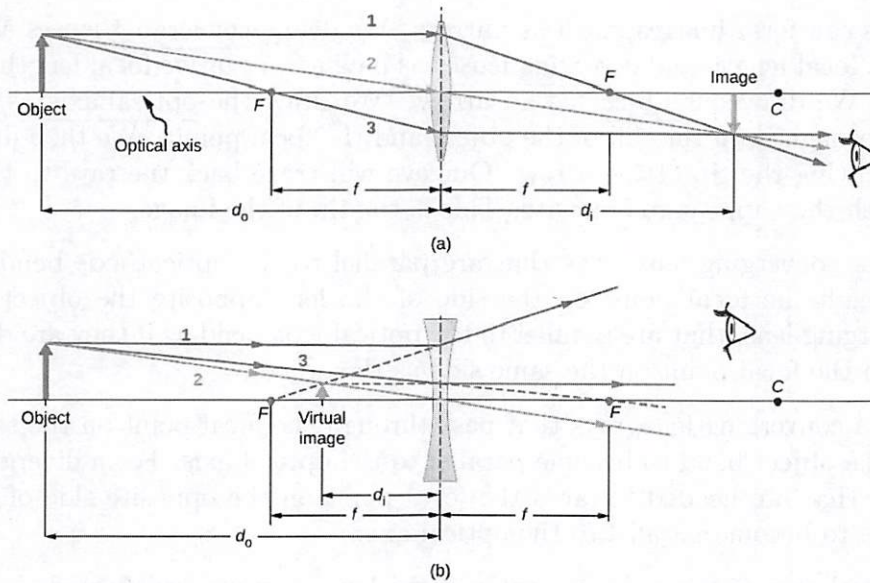


Figure 1:

Figure 2.21 from *OpenStax University Physics Volume 3*. Read for free at openstax.org.

We have a converging lens with $f = +12$ cm.

(a) The object distance is 18 cm. What is the magnification? Is this image real or virtual?

$$\frac{1}{18\text{cm}} + \frac{1}{s'} = \frac{1}{12\text{cm}}$$

$$s' = 36\text{cm} \quad m = -\frac{36\text{cm}}{18\text{cm}}$$

$$m = -2$$

(b) The object distance is 6 cm. What is the magnification? Is this image real or virtual?

$$\frac{1}{6\text{cm}} + \frac{1}{s'} = \frac{1}{12\text{cm}}$$

$$s' = -12\text{cm}$$

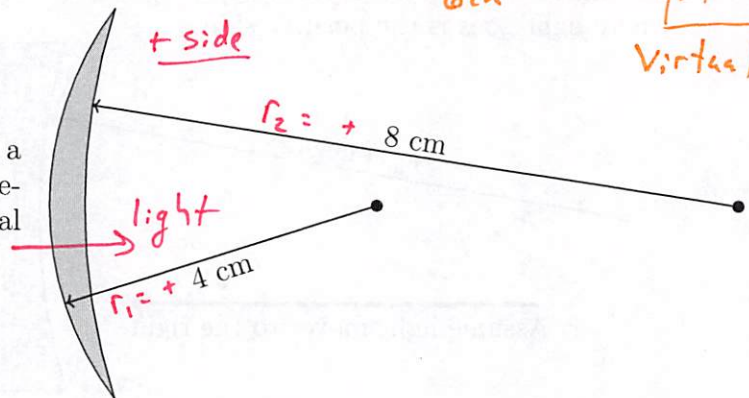
$$m = -\frac{-12\text{cm}}{6\text{cm}} = +2$$

$$m = +2$$

Real

Virtual

The lens at right is made of a material with an index of refraction of 1.6. What is its focal length?



$$\frac{1}{f} = \left(\frac{1.6}{1} - 1\right) \left(\frac{1}{4\text{cm}} - \frac{1}{8\text{cm}}\right)$$

$$f = +13.3\text{cm}$$