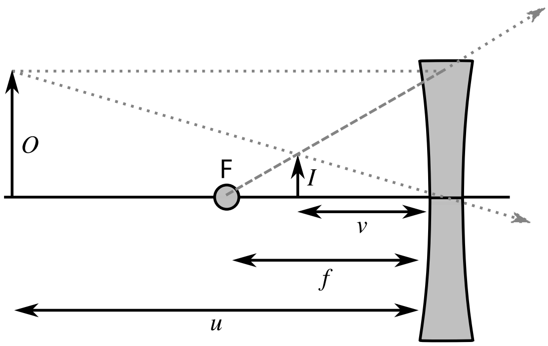
## 49 Concave Lenses ♡

In the diagram below, the object has size $O$, the image size $I$, and the lens has a focal length $f$. The lens now causes the rays to diverge. We can work out the location of the image by drawing two rays through the system.

1. A ray passing through the centre of the lens that does not bend.
2. A ray travelling parallel to the axis will bend at the lens so that it appears to come from the focal point F (distance $f$ from the lens). On the diagram, we draw a dotted line from F to the lens, and a solid line from there on.
3. The image $I$ is drawn where the lines cross.
4. The object distance is labelled $u$. The image distance is labelled $v$.




49.1 Copy and complete the ray diagrams by drawing the path of each ray of light after passing through the lens and hence find the position, size and orientation of the image. State whether the image formed is real or virtual.


The power formula $P = 1/f$ is used for concave lenses, just as it is for convex lenses. However concave lens powers are negative. When giving the power of a lens, always give the sign to make it clear whether you mean a convex or concave lens.

Example 1 – Calculate the power of a concave lens with a focal length of $4.0$ cm.

$$4.0 \text{ cm} = 0.04 \text{ m} \quad P = 1/f = 1/0.040 = 25 \text{ D}$$

This is a concave lens, so we use a negative power $P = -25$ D.

Example 2 – Calculate the focal length of a -0.8 D lens. The power is negative, so this is a concave lens.

$$P = 1/f, \text{ so } f = 1/P = 1/(0.8 \text{ D}) = 1.25 \text{ m}$$

49.2 Use the equation $P = f^{-1}$ to work out the power in dioptres of lenses with the following focal lengths:

(a) convex, $f = 1.6$ m.

(b) concave , $f = 2.0$ m.

(c) convex, $f = 5.0$ cm.

(d) concave, $f = 7.0$ cm.

49.3 Calculate the focal length, and say whether it is concave or convex.

(a) A $-2.5$ D lens.

(b) A $-1.5$ D lens.

(c) A $+20$ D lens.

(d) A $-40$ D lens.

We use similar triangles in the diagram of page 148 to form two equations for $O/I$. The ray through the middle of the lens yields:

$$\frac{O}{I} = \frac{u}{v}$$

Using the line from F to the lens via the top of $I$, we can also write:

$$\frac{O}{I} = \frac{f}{f-v}$$

Equating the two expressions:

$$\frac{u}{v} = \frac{f}{f-v} \Rightarrow \frac{v}{u} = \frac{f-v}{f} \Rightarrow \frac{v}{u} = 1 - \frac{v}{f}$$
$$\Rightarrow \frac{1}{u} = \frac{1}{v} - \frac{1}{f} \Rightarrow \frac{1}{v} = \frac{1}{u} + \frac{1}{f}$$

This is the same as the equation on page 146 for a convex lens, if you flip the signs of $f$ and $v$. Making $v$ negative makes sense given that our image is to the left of the lens. Making $f$ negative also makes sense as we remember that $P = 1/f$ and concave lenses have negative powers.

- For all lenses $1/v = 1/f - 1/u$, where
- a negative $v$ means that the image is to the left of the lens, and
- a negative value of $f$ means that the lens is concave.

49.4 Use a scale diagram, or the formula, to work out the image distance for each situation below. Assume that you have a $5.0$ cm concave lens ($f = -5.0$ cm), and that the object height is $8.0$ cm.

(a) Object distance = $20$ cm
(b) Object distance = $10$ cm
(c) Object distance = $15$ cm
(d) Object distance = $4.0$ cm

As with convex lenses, the magnification = $I/O = v/u$, where we ignore the sign of $v$.

49.5 Work out the image distance and magnification for the following lenses, and state whether the image is real or virtual.

(a) A concave lens with $10$ cm focal length, $20$ cm object distance.
(b) A concave lens with $20$ cm focal length, $10$ cm object distance.
(c) A convex lens with $30$ cm focal length, $60$ cm object distance.
(d) A convex lens with $40$ cm focal length, $30$ cm object distance.
(e) A convex lens with $50$ cm focal length, $75$ cm object distance.
(f) A convex lens with $60$ cm focal length, $1.5$ m object distance.



A concave lens makes a parallel beam if $u = f$. Otherwise it makes a virtual, diminished image.