

Reflection, refraction and images from mirrors and lenses

AP Physics 2 (algebra-based) · Lesson

Quick answer: Geometric optics treats light as rays. Reflection obeys $\theta_r = \theta_i$, refraction obeys Snell's law $n_1 \sin \theta_1 = n_2 \sin \theta_2$, and mirrors and thin lenses obey $1/d_o + 1/d_i = 1/f$ with magnification $m = -d_i/d_o$. The signs of f and d_i tell you whether an image is real or virtual.

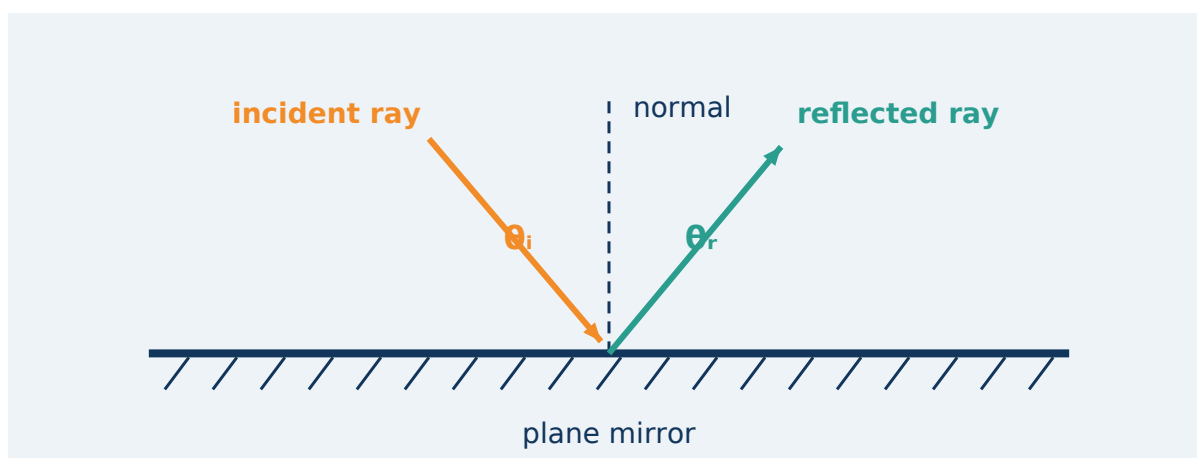
Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 13

How does reflection work?

When light hits a smooth surface, it bounces off in a predictable direction. Angles are always measured from the **normal**, a line at right angles to the surface at the point of contact.

Key law

Law of reflection: the angle of reflection equals the angle of incidence, $\theta_r = \theta_i$, and the incident ray, reflected ray and normal lie in the same plane.



Both angles are measured from the normal, not from the mirror surface.

A plane mirror forms a virtual image as far behind the mirror as the object is in front. Curved mirrors follow the mirror equation $1/d_o + 1/d_i = 1/f$, where the focal length is half the radius of curvature, $f = R/2$. A concave mirror has $f > 0$ and a convex mirror has $f < 0$.

What does Snell's law say about refraction?

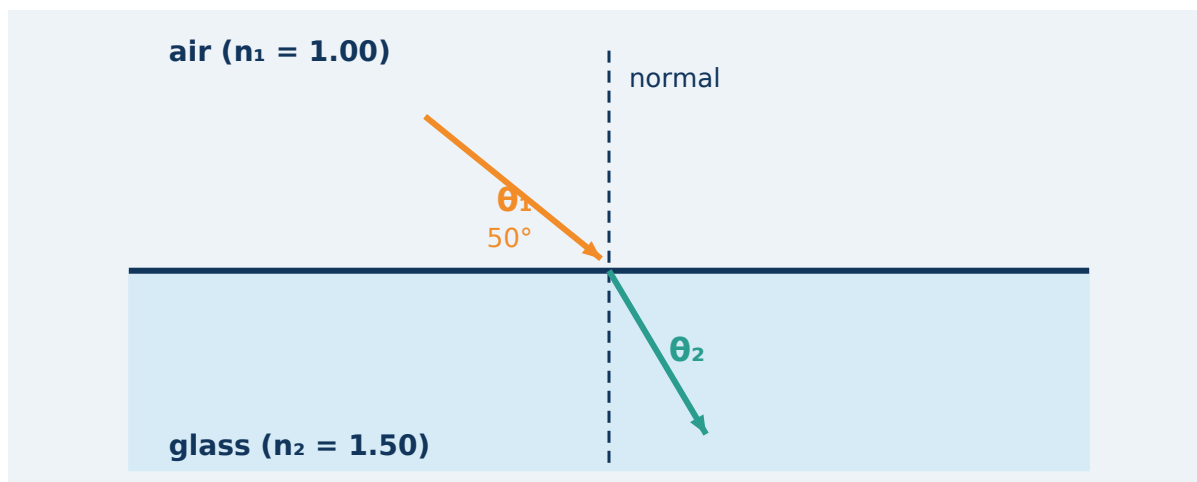
Definition

Refraction is the change of direction of light when it passes between media in which it travels at different speeds. The **refractive index** of a medium is $n = c/v$, where $c = 3.00 \times 10^8$ m/s is the speed of light in vacuum.

Formula

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

n = refractive index (no unit), θ = angle from the normal (degrees). Light bends towards the normal when it enters a medium with a larger n .



Entering glass, the ray slows down and bends towards the normal.

Medium	Refractive index n	Speed of light (10^8 m/s)
Air	1.00	3.00
Water	1.33	2.26
Glass (typical)	1.50	2.00
Diamond	2.42	1.24

Worked example

Light in air hits water at 40° to the normal. Find the angle of refraction.

$$1.00 \times \sin 40^\circ = 1.33 \times \sin \theta_2, \text{ so } \sin \theta_2 = 0.6428 / 1.33 = 0.4833 \text{ and } \theta_2 = \mathbf{29^\circ}.$$

When light moves from a higher index to a lower index, it bends away from the normal. Above a certain angle, no light leaves at all and the ray is totally reflected. The smallest angle of incidence that gives total internal reflection is the critical angle, with $\sin \theta_c = n_2/n_1$.

Worked example

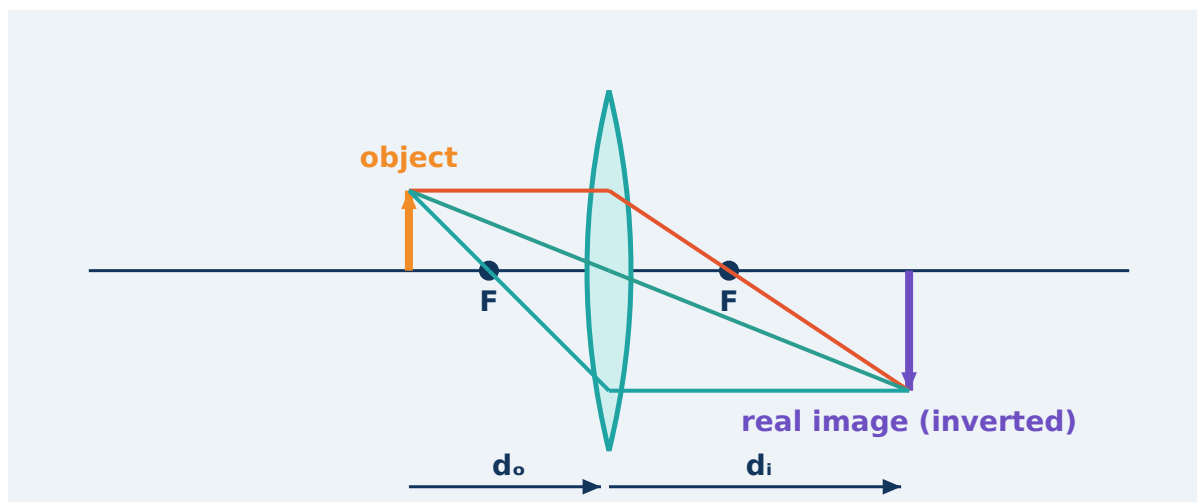
Find the critical angle for glass ($n = 1.50$) in air.

$$\sin \theta_c = 1.00 / 1.50 = 0.667, \text{ so } \theta_c = \mathbf{42^\circ}. \text{ Rays hitting the glass-air boundary at more than } 42^\circ \text{ are totally reflected, which is how fibre optic cables trap light.}$$

How does a thin lens form an image?

A converging lens bends parallel rays to a focal point at distance f . To locate an image, draw two or three principal rays from the top of the object: one parallel to the axis then through the

far focus, one through the centre of the lens undeviated, and one through the near focus then parallel to the axis. Where the rays meet is the image.



An object beyond F gives a real, inverted image. The three principal rays meet at its tip.

Formula

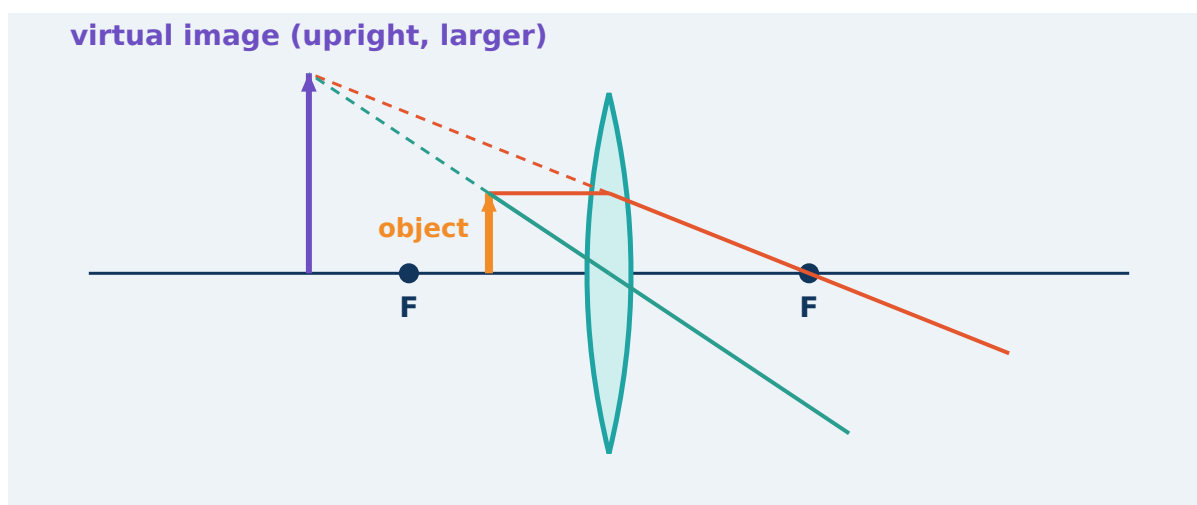
$$1/d_o + 1/d_i = 1/f \text{ and } m = h_i/h_o = -d_i/d_o$$

d_o = object distance, d_i = image distance (both in the same unit), f = focal length, m = magnification. Use $f > 0$ for a converging lens and $f < 0$ for a diverging lens. A positive d_i means a real image; a negative d_i means a virtual image. A negative m means the image is inverted.

Worked example

Mei in Singapore uses a converging lens of $f = 12$ cm. An object is 30 cm from it. Find the image.

$1/d_i = 1/12 - 1/30 = 3/60$, so $d_i = \mathbf{20 \text{ cm}}$. $m = -20/30 = \mathbf{-0.67}$: the image is real, inverted and reduced.



Inside the focal length the lens acts as a magnifier: the image is virtual, upright and larger.

Worked example

The same lens, $f = 12$ cm, with the object at 8.0 cm.

$1/d_i = 1/12 - 1/8 = -1/24$, so $d_i = -24$ cm (virtual, on the object side). $m = +24/8.0 = +3.0$: upright and three times larger.

Object distance (converging lens)	Image	Size
$d_o > 2f$	real, inverted	smaller
$f < d_o < 2f$	real, inverted	larger
$d_o < f$	virtual, upright	larger

Common mistake

Measuring angles from the surface instead of from the normal. Another is using the wrong sign for d_i : a virtual image has a negative image distance, so a calculator answer of -24 cm is not an error.

Lina's tip

Before any calculation, sketch the three principal rays. If your calculated image does not match your sketch, check the signs of f and d_i .

Key points to remember

- Law of reflection: $\theta_r = \theta_i$, measured from the normal
- Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$, with $n = c/v$
- Critical angle: $\sin \theta_c = n_2/n_1$ when n_1 is larger than n_2
- Thin lens and mirror equation: $1/d_o + 1/d_i = 1/f$
- Magnification: $m = h_i/h_o = -d_i/d_o$; negative m means inverted

Reflection, refraction and images from mirrors and lenses: frequently asked questions

What is the difference between a real and a virtual image?

A real image is formed where light rays actually meet and can be projected onto a screen. A virtual image is where rays only appear to come from, so no screen can show it.

Why does light bend when it enters glass?

Light travels more slowly in glass than in air. When a ray meets the boundary at an angle, one side of the wavefront slows first, which turns the ray towards the normal.

When does total internal reflection happen?

It happens when light travels from a medium of higher index to one of lower index and the angle of incidence is larger than the critical angle. No light is refracted out.

What does a negative magnification mean?

It means the image is inverted compared with the object. The size of the magnification, taken without the sign, tells you whether the image is larger or smaller than the object.

Why do converging and diverging lenses have opposite signs of focal length?

A converging lens brings parallel rays to a real focus, so f is positive. A diverging lens spreads rays so they appear to come from a virtual focus, so f is negative.