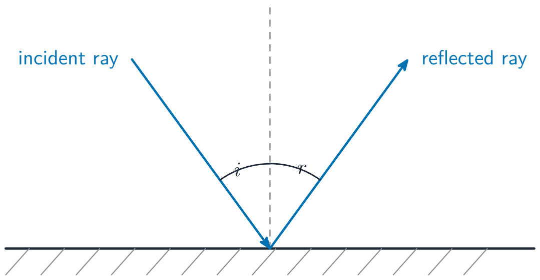
Geometric Optics

AP Physics 2

Reflection

Geometric optics 几何光学 treats light as straight-line rays. The **law of reflection** 反射定律: when light bounces off a surface, the **angle of incidence** 入射角 equals the **angle of reflection** 反射角, both measured from the **normal** (the line perpendicular to the surface). Smooth surfaces reflect a clear image; rough surfaces scatter the rays.



The law of reflection: the angle of incidence equals the angle of reflection

Images Formed by Mirrors

A curved mirror focuses parallel rays at its **focal point**, a distance f from the mirror. The **mirror equation** relates object and image distances:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}, \qquad m = -\frac{d_i}{d_o}.$$

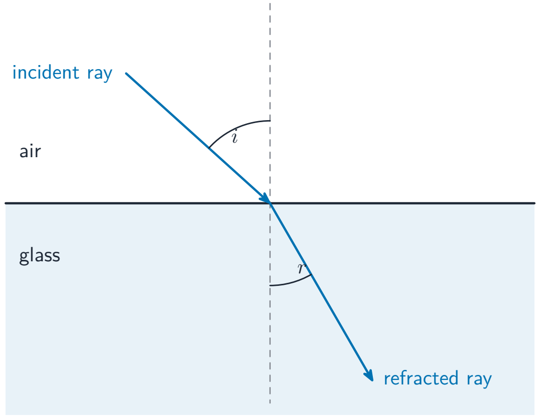
A **concave mirror** 凹面镜 (converging) can form a **real image** 实像 (rays actually meet, projectable, inverted); a **convex mirror** 凸面镜 always forms a **virtual image** 虚像 (rays only appear to meet, upright, reduced). The **magnification** m gives the image's size and orientation. Sign convention matters: a **negative** image distance means a virtual image behind the mirror or lens.

Refraction

Light bends when it passes between materials because its speed changes – **refraction** 折射. Each material has an **index of refraction** 折射率 $n = \frac{c}{v}$ (how much it slows light). **Snell's law** 斯涅尔定律:

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

Light entering a denser medium (larger n) bends **toward** the normal. Beyond a critical angle, light going to a less-dense medium reflects entirely – **total internal reflection** 全反射, used in fibre optics.



Light refracts, bending towards the normal as it enters glass

Worked example. A ray in air ($n_1 = 1.00$) strikes water ($n_2 = 1.33$) at 40° to the normal. By Snell's law,

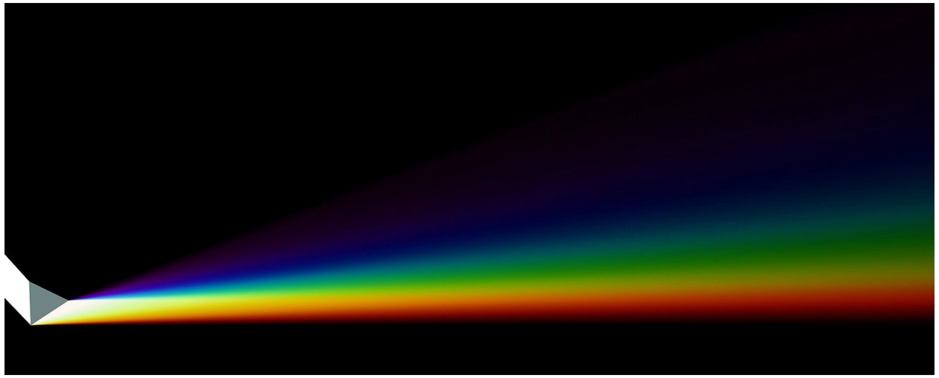
$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 = \frac{1.00}{1.33}\sin 40^\circ = 0.483 \;\Rightarrow\; \theta_2 = 29^\circ.$$

The ray bends toward the normal, as expected going into the denser medium.

Worked example (critical angle). For light trying to leave glass ($n = 1.50$) for air, total internal reflection begins at the critical angle θ_c where the refracted ray grazes the surface:

$$\sin\theta_c = \frac{1}{n} = \frac{1}{1.50} = 0.667 \;\Rightarrow\; \theta_c = 42^\circ.$$

Any ray hitting the inside surface more steeply than 42° is trapped – the reason optical fibres carry light for kilometres.



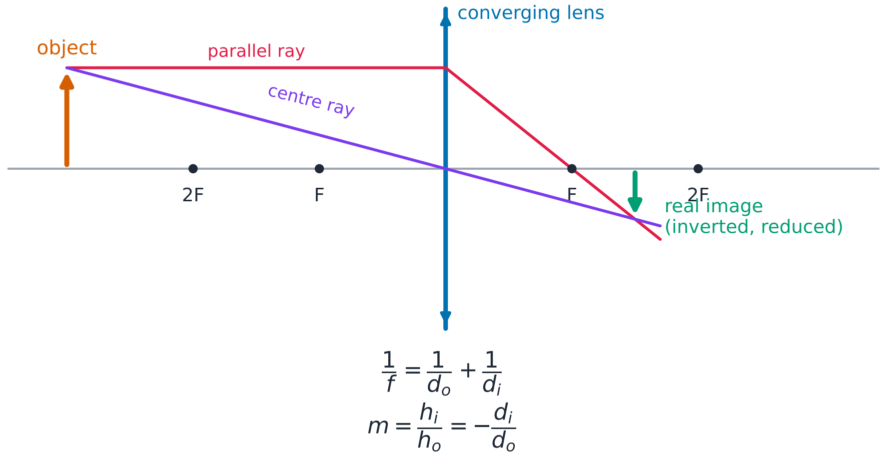
Refraction bends each colour by a different amount, so a prism spreads white light into a rainbow

Images Formed by Lenses

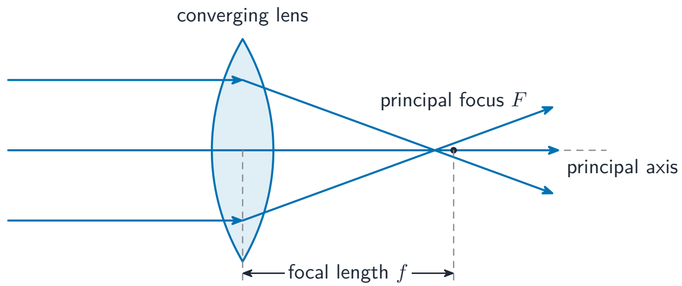
A **lens** bends light through refraction. The **thin-lens equation** has the same form as the mirror equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}, \qquad m = -\frac{d_i}{d_o}.$$

A **converging** 会聚 (convex) lens can form a real, inverted image or, for a close object, a virtual, upright, enlarged image (a magnifying glass). A **diverging** 发散 (concave) lens always forms a virtual, upright, reduced image. Ray diagrams locate the image quickly using two easy rays: one parallel to the axis that bends to pass through the far focus, and one straight through the centre of the lens (undeviated).



Two rays locate the image: parallel-then-focus, and straight through the centre



A converging lens brings parallel rays to its principal focus

Worked example. An object sits 30 cm from a converging lens of focal length $f = 10$ cm. Find the image. From the thin-lens equation,

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{10} - \frac{1}{30} = \frac{2}{30} \Rightarrow d_i = 15 \text{ cm},$$

and the magnification is $m = -d_i/d_o = -15/30 = -0.5$. The image is real (positive d_i), inverted (negative m), and half the object's size – just what a camera lens does.

A convex lens forms a real, inverted image of a distant scene, exactly as the ray diagram predicts

Exam tips

- Measure all angles from the **normal**, not the surface.
- Light entering a **denser** medium (larger n) bends **toward** the normal; use Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$.
- Total internal reflection happens only going into a **less** dense medium, beyond the critical angle ($\sin\theta_c = 1/n$).
- For mirrors and lenses use $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ and $m = -d_i/d_o$: a **positive** d_i is a real image, negative is virtual.
- $n = c/v$, so a bigger index means a slower speed of light in the material.