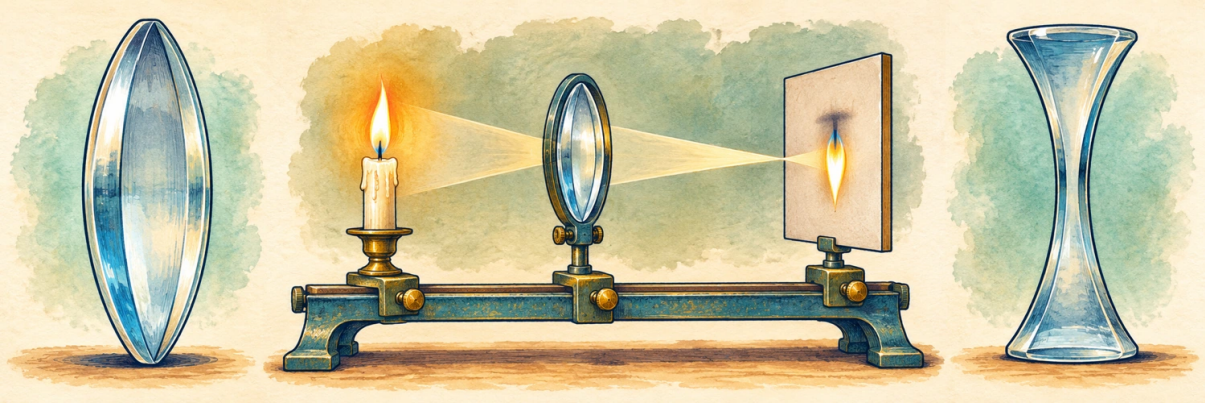
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GRADE 10 / SCIENCE

Chapter 9

Light – Reflection and Refraction



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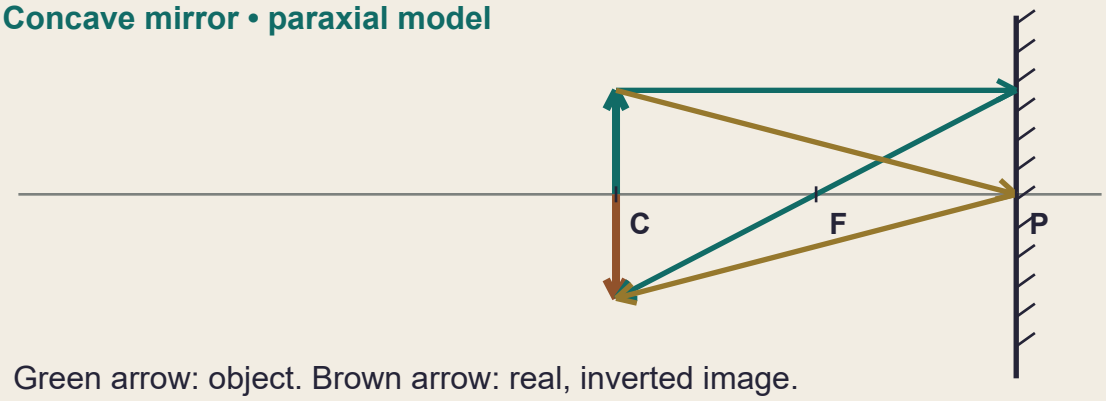
05 Lens formula and power

Light – Reflection and Refraction

Spherical mirrors

A concave mirror can converge rays. A convex mirror diverges rays from a real object. Interpret the signs using the direction of the incoming light.

Concave mirror • paraxial model



Green arrow: object. Brown arrow: real, inverted image.

Geometry

P is the pole, C the centre of curvature and F the principal focus. For paraxial rays from a spherical mirror, the focal length is approximately half its radius of curvature.

Real and virtual

Reflected rays meet at a real image. Their backward extensions can meet behind the mirror at a virtual image. A convex mirror gives an upright, diminished image of a real object.

WORKED EXAMPLE

A 4 cm object is 20 cm in front of a concave mirror with f = −10 cm. Find its image.

1/v = 1/f − 1/u = −1/10 + 1/20 = −1/20, so v = −20 cm. Magnification m = −v/u = −1. Image height is −4 cm: real, inverted and the same size.

SELF-CHECK

A 6 cm object is 30 cm in front of a convex mirror with f = +15 cm. Where is the image?

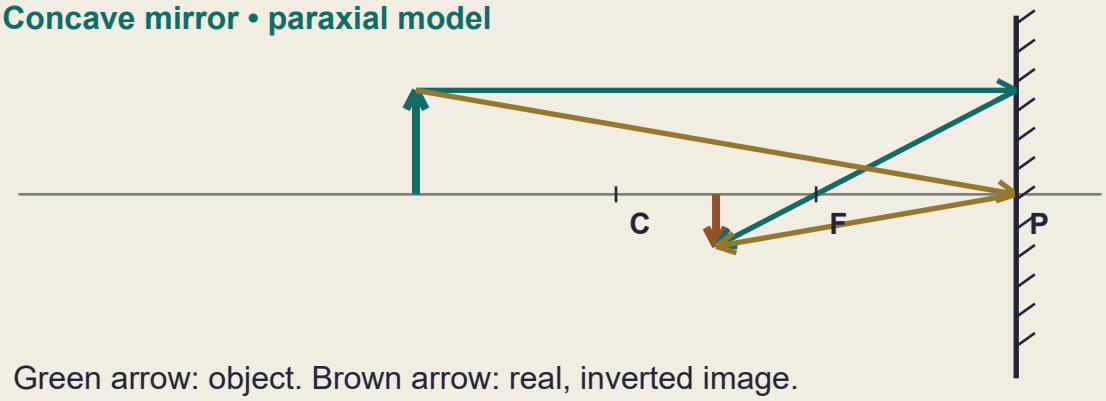
1/v = 1/15 + 1/30 = 1/10. The image is 10 cm behind the mirror. m = +1/3, so it is upright and 2 cm tall.

Light – Reflection and Refraction

Mirror numericals

Use the mirror formula with signed distances measured from the pole. Keep a single unit throughout the calculation.

Concave mirror • paraxial model



Green arrow: object. Brown arrow: real, inverted image.

Set the signs

With incident light travelling left to right, a real object on the left has $u < 0$. A concave mirror has $f < 0$. A convex mirror has $f > 0$.

Interpret magnification

Use $m = -v/u$. For a real object, $m < 0$ means inverted, and $m > 0$ means upright. The magnitude gives the image-to-object height ratio.

WORKED EXAMPLE

A concave mirror has f = −10 cm and u = −30 cm. Find v and m.

$1/v = -1/10 + 1/30 = -1/15$. Thus $v = -15$ cm and $m = -(-15)/(-30) = -0.5$. The real image is inverted and half-size.

SELF-CHECK

For a convex mirror, u = −20 cm and f = +10 cm. Find the image distance.

$1/v = 1/10 + 1/20 = 3/20$. Thus $v = +20/3$ cm, about +6.67 cm. The positive magnification of 1/3 means upright and diminished.

Refraction and index

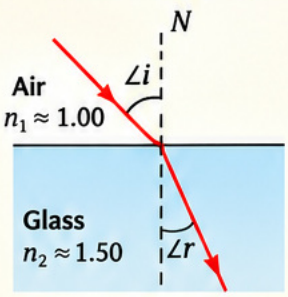
Refraction: key ideas

Refraction is the change in direction (bending) of light when it passes between two transparent media because its speed changes.

- **Normal:** imaginary line perpendicular to the interface at the point of incidence.
- $\angle i$: angle between the incident ray and normal (angle of incidence).
- $\angle r$: angle between the refracted ray and normal (angle of refraction).

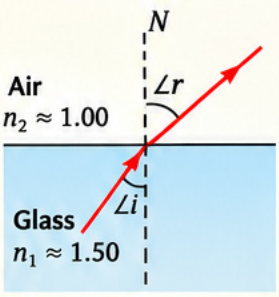
Air ↔ Glass: bending of light

Air to glass (denser)



Bends towards the normal ($\angle r < \angle i$).

Glass to air (rarer)



Bends away from the normal ($\angle r > \angle i$).

Refractive index and Snell's law

- **Refractive index (n)** of a medium:

$$n = \frac{c}{v}$$

$c = 3.0 \times 10^8\ \text{m s}^{-1}$ (speed of light in vacuum/air), v = speed of light in the medium.

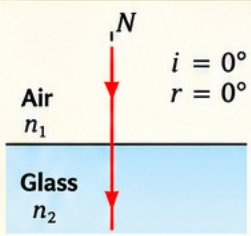
- **Snell's law** (for two media 1 and 2):

$$n_1 \sin i = n_2 \sin r$$

So, $\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$ (ratio is constant for the pair of media and for a given colour).

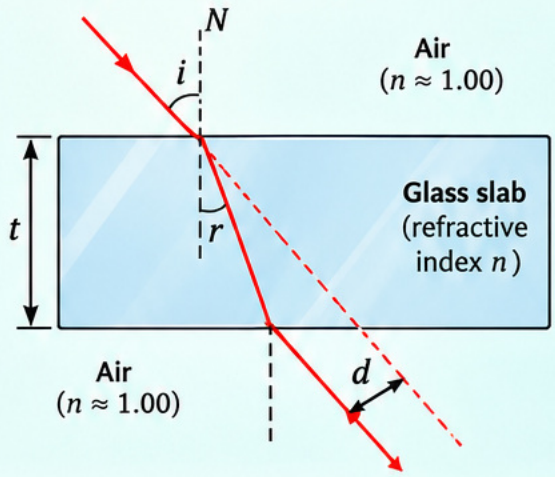
Normal incidence

- If the ray is incident along the normal ($i = 0°$), then $r = 0°$.
- The ray goes straight without any deviation, though its speed changes.



Parallel glass slab: lateral shift

A ray passing through a parallel-sided glass slab emerges parallel to the incident ray but is displaced sideways by a distance d (lateral shift).



Lateral shift: $d = \frac{t \sin (i - r)}{\cos r}$ t = thickness of slab.

Worked example (reasoning)

A ray from air ($n_1 = 1.00$) enters glass ($n_2 = 1.50$) with $\angle i = 30°$. Find $\angle r$.

Solution:

Using Snell's law, $n_1 \sin i = n_2 \sin r$,

$$\sin r = \frac{n_1}{n_2} \sin i = \frac{1.00}{1.50} \times \sin 30°$$

$$= \frac{1}{1.50} \times 0.5 = 0.333...$$

$$\Rightarrow r = \sin^{-1}(0.333...) \approx \mathbf{19.5°}.$$

Self-check

Q. For glass ($n = 1.50$), find the speed of light in glass. Also, when a ray is incident normally on a glass slab, what is the deviation?

Answer:

Speed: $v = \frac{c}{n} = \frac{3.0 \times 10^8}{1.50}$

$= 2.0 \times 10^8\ \text{m s}^{-1}$.

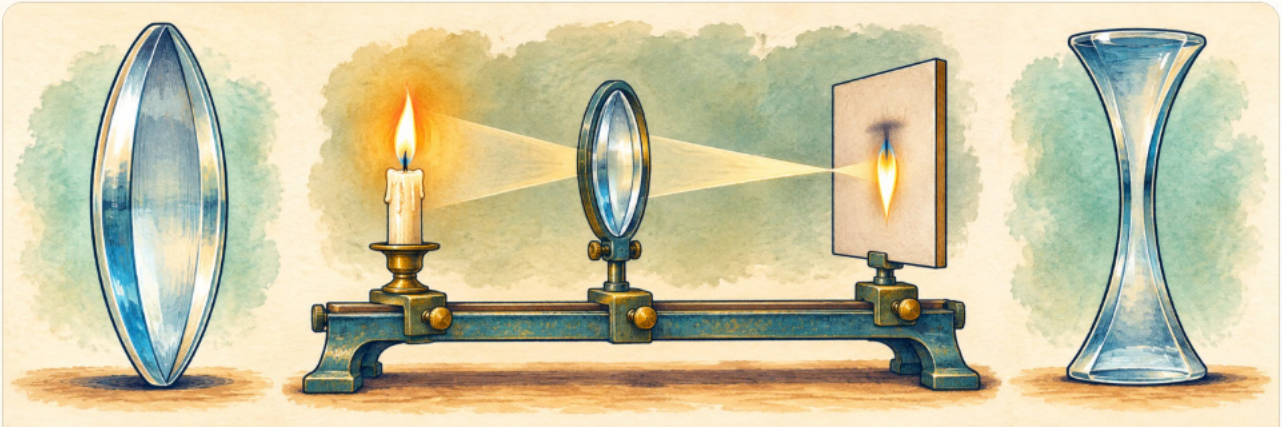
Deviation: 0° (the ray goes straight).



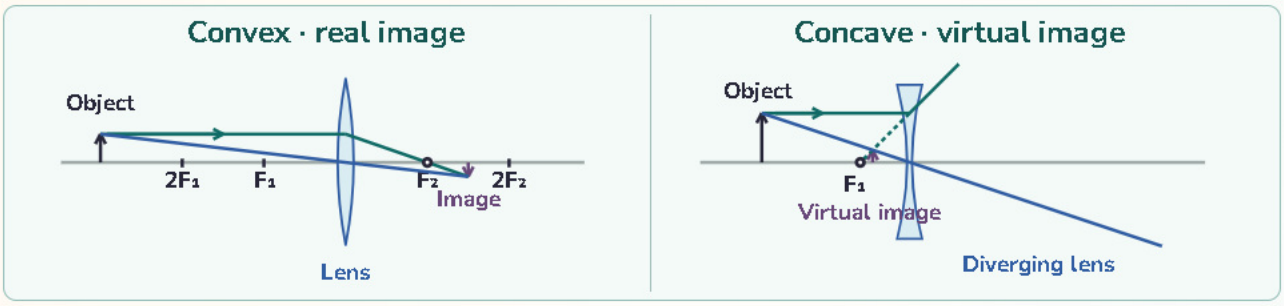
Apparent bending (refraction)

Lens ray diagrams

Two rays from the same object point locate its image. Follow the refracted rays for a real image and their backward extensions for a virtual image.



Convex lens | Object, lens and screen | Concave lens



Parallel ray

At a convex lens, a ray parallel to the principal axis emerges through the far focus. At a concave lens, it appears to come from the near focus.

Central ray

A ray through the optical centre of an ideal thin lens continues straight. Where the two refracted rays meet gives the image tip.

Convex lens

An object beyond 2F makes a real, inverted, smaller image. Inside F, the image is virtual, upright and magnified on the object side.

Concave lens

For a real object, the outgoing rays diverge. Their backward extensions meet between the lens and its near focus, giving an upright, smaller virtual image.

WORKED EXAMPLE

An object is 30 cm from a convex lens of focal length 10 cm. Where is its image?

$1/v = 1/10 - 1/30 = 1/15$. So $v = +15$ cm and $m = 15/(-30) = -0.5$. The image is real, inverted and half-size.

SELF-CHECK

Can the virtual image from a concave lens be caught on a screen?

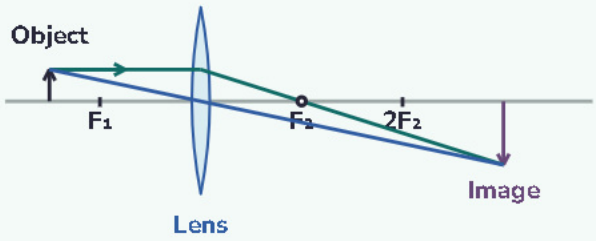
No. Only the backward extensions meet at the virtual image.

Lens formula and power

A lens can make an image larger even when its power stays fixed. Power depends on focal length. Magnification also depends on the object position.



Object	Converging lens	Screen for a real image



1/f = 1/v − 1/u • m = v/u • P (D) = 1/f (f in metres)

u = −30 cm • f = +20 cm • v = +60 cm

Set the signs

Take the optical centre as the origin. For light travelling left to right, right is positive. A real object on the left has negative u.

Read the result

With a real object on the left, positive v locates a real image on the right. Negative m means the image is inverted. Its magnitude gives the size factor.

Calculate power

A converging lens with f = +20 cm has P = 1/(+0.20 m) = +5 D. A diverging lens has negative focal length and negative power.

Trace the rays

The parallel ray bends through the far focus. The central ray continues straight. Both reach the same point at the tip of the image in the drawing.

WORKED EXAMPLE

Find v and m for u = −30 cm and f = +20 cm.

1/v = 1/20 − 1/30 = 1/60. Thus v = +60 cm and m = 60/(−30) = −2. The image is real, inverted and twice as tall.

SELF-CHECK

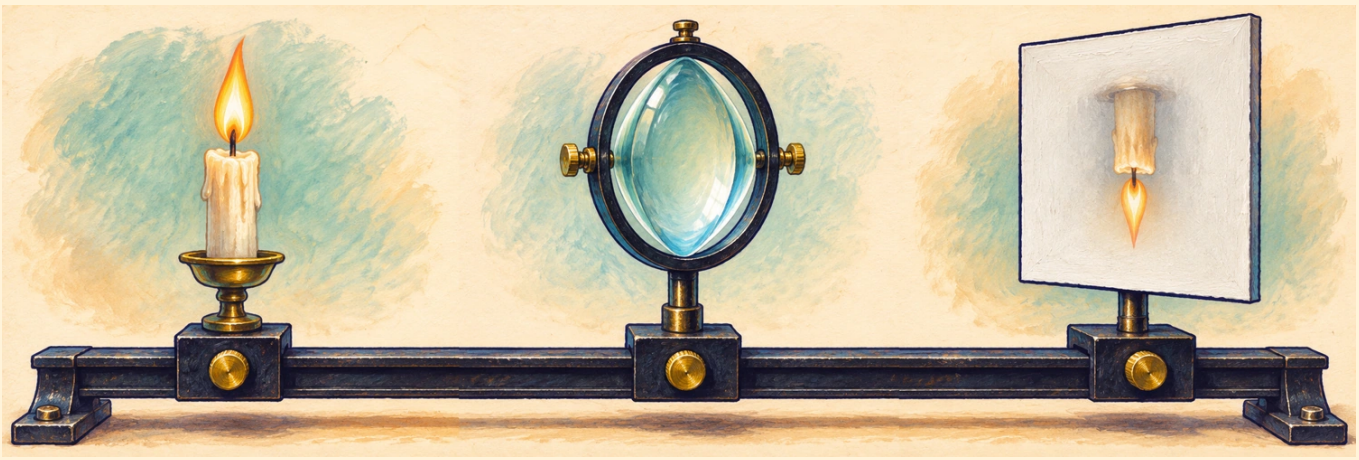
What is the power of a diverging lens with f = −25 cm?

Convert to metres first. P = 1/(−0.25 m) = −4 D.

ONE LAST CHALLENGE

Can a flame point down?

A candle, a converging lens and a screen sit on an optics bench. How can the screen show an upside-down flame?



THE REVEAL

The rays cross.

With the candle beyond the focal point, rays from its tip converge below the optical axis. A screen at that distance catches a real, inverted image.

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